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(54) **CARBONIZATION APPARATUS AND METHOD FOR PRODUCING CARBON FIBER**

(57) In order to provide a carbonization apparatus capable of performing commercial-scale carbonization of a plurality of precursor fibers, a carbonization apparatus 1 for carbonizing a plurality of precursor fibers of carbon fibers through heating includes: a microwave generator 11 that generates microwaves; cavities 13 that are connected in series and into which the generated microwaves are introduced; two or more structures 14 that are arranged in series within the cavities

13 and inside which the plurality of precursor fibers can move in parallel, wherein the structures 14 partially absorb microwaves introduced from the outside, and partially transmit the microwaves inward, and the two or more structures 14 are irradiated with microwaves such that a structure 14 on a later-stage side along a movement direction of the plurality of precursor fibers reaches a higher temperature.

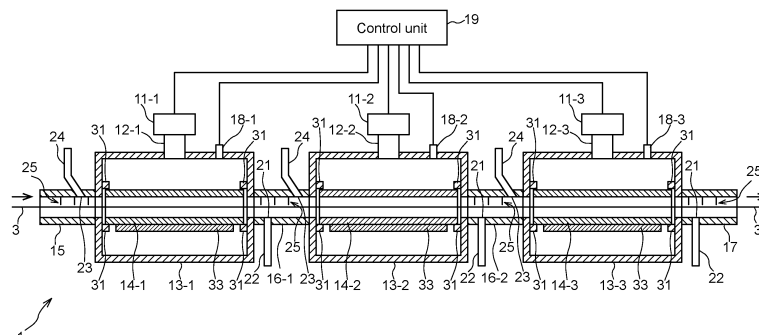


FIG. 2

Description

Technical Field

[0001] The present invention relates to a carbonization apparatus for carbonizing precursor fibers of carbon fibers, and a method for producing carbon fibers.

Background Art

[0002] Carbon fibers are produced by first thermally stabilizing precursor fibers of carbon fibers through heating at 200 to 300°C in air, and then carbonizing the thermally stabilized precursor fibers through heating at 1000°C or higher in an inert atmosphere such as nitrogen. For example, microwaves are used as a method for heating in the carbonization.

Summary of Invention

Technical Problem

[0003] However, the carbonization of precursor fibers by microwave heating has been carried out only on a small laboratory scale, and it has been difficult to commercially produce carbon fibers.

[0004] The present invention has been made in view of the above-described circumstances, and it is an object thereof to provide a carbonization apparatus and a method for producing carbon fibers, which enable commercial-scale carbonization of a plurality of precursor fibers.

Solution to Problem

[0005] In order to achieve the above-described object, an aspect of the present invention is directed to a carbonization apparatus for carbonizing a plurality of precursor fibers of carbon fibers through heating, including: two or more microwave generators that generate microwaves; one or two or more cavities into which microwaves generated by the two or more microwave generators are introduced; and two or more structures that are arranged in series within the one or two or more cavities and inside which the plurality of precursor fibers can move in parallel, wherein each of the two or more structures partially absorbs microwaves introduced from the outside, and partially transmits the microwaves inward, and the two or more structures can be irradiated with microwaves such that a structure on a later-stage side along a movement direction of the plurality of precursor fibers reaches a higher temperature.

[0006] Furthermore, the carbonization apparatus according to an aspect of the present invention may be such that at least one structure of the two or more structures can be irradiated with microwaves such that the structure reaches a temperature equivalent to a

target temperature of the plurality of precursor fibers moving inside the structure.

[0007] Furthermore, the carbonization apparatus according to an aspect of the present invention may be such that each of the two or more structures has a hollow pillar-like shape.

[0008] Furthermore, the carbonization apparatus according to an aspect of the present invention may be such that the one or two or more cavities are two or more cavities connected in series, the microwaves generated by the two or more microwave generators are respectively introduced into the two or more cavities, and the two or more structures are respectively arranged within the two or more cavities.

[0009] Furthermore, the carbonization apparatus according to an aspect of the present invention may be such that a discharge port is provided between adjacent cavities among the two or more cavities to discharge gas generated in an earlier-stage cavity of the adjacent cavities.

[0010] Furthermore, the carbonization apparatus according to an aspect of the present invention may be such that a supply port is provided between adjacent cavities among the two or more cavities to supply inert gas into a later-stage cavity of the adjacent cavities.

[0011] Furthermore, the carbonization apparatus according to an aspect of the present invention may be such that a needle array circuit is provided between adjacent cavities among the two or more cavities to prevent propagation of microwaves between the adjacent cavities.

[0012] Furthermore, the carbonization apparatus according to an aspect of the present invention may be such that the carbonization apparatus further includes an electrical conduction unit that electrically interconnects the carbon fibers in the vicinity of a discharge port of a last-stage cavity of the one or two or more cavities.

[0013] Furthermore, the carbonization apparatus according to an aspect of the present invention may be such that a last-stage structure of the two or more structures contains silicon nitride.

[0014] Furthermore, an aspect of the present invention is directed to a method for producing carbon fibers by carbonizing a plurality of precursor fibers of carbon fibers through heating, including: moving the plurality of precursor fibers in parallel inside two or more structures that are arranged in series within the one or two or more cavities, each of the two or more structures partially absorbing microwaves introduced from the outside and partially transmitting the microwaves inward; and irradiating the two or more structures with microwaves such that a structure on a later-stage side along a movement direction of the plurality of precursor fibers reaches a higher temperature.

Advantageous Effects of Invention

[0015] With the carbonization apparatus and the

method for producing carbon fibers according to an aspect of the present invention, a plurality of precursor fibers can be simultaneously carbonized by microwave heating, and thus it is possible to commercially produce carbon fibers.

Brief Description of Drawings

[0016]

FIG. 1 is a schematic diagram showing the configuration of a carbonization apparatus according to an embodiment of the present invention.

FIG. 2 is a schematic longitudinal cross-sectional view showing an internal structure of the carbonization apparatus in the embodiment.

FIG. 3A is a perspective view showing a structure in the embodiment.

FIG. 3B is a longitudinal cross-sectional view showing a cavity and the structure in the embodiment.

FIG. 3C is a longitudinal cross-sectional view showing the cavity and the structure in the embodiment.

FIG. 4A is a longitudinal cross-sectional view showing a needle array circuit in the embodiment.

FIG. 4B is a transverse cross-sectional view showing the needle array circuit in the embodiment.

FIG. 5 is a longitudinal cross-sectional view showing an electrical conduction unit in the embodiment.

FIG. 6 is a schematic longitudinal cross-sectional view showing another example of the configuration of the carbonization apparatus in the embodiment.

FIG. 7 is a longitudinal cross-sectional view showing another example of the structure in the embodiment.

FIG. 8 is a longitudinal cross-sectional view showing another example of the structure in the embodiment.

Description of Embodiment

[0017] Hereinafter, a carbonization apparatus and a method for producing carbon fibers according to the present invention will be described based on an embodiment. Note that constituent elements denoted by the same reference numerals are the same as or similar to each other in the following embodiments, and thus a description thereof may not be repeated. With the carbonization apparatus according to this embodiment, two or more structures that are arranged in series within a cavity are heated with microwaves, and a plurality of precursor fibers that are arranged in parallel and move inside the two or more structures are directly heated with microwaves transmitted through the structures, and thus the plurality of precursor fibers are carbonized.

[0018] FIG. 1 is a schematic diagram showing an external appearance of a carbonization apparatus 1 according to an embodiment of the present invention, and FIG. 2 is a schematic longitudinal cross-sectional view showing an internal structure of the carbonization apparatus 1. In FIG. 1, the configurations of a control unit 19 and the like are omitted. In the examples of FIGS. 1 and 2, the carbonization apparatus 1 includes microwave generators 11-1, 11-2, and 11-3 that generate microwaves, waveguides 12-1, 12-2, and 12-3 that respectively guide the two or more generated microwaves, cavities 13-1, 13-2, and 13-3 that are connected in series and into which the two or more guided microwaves are respectively introduced, and structures 14-1, 14-2, and 14-3 that are respectively arranged within the cavities 13-1, 13-2, and 13-3. If the microwave generators 11-1, 11-2, and 11-3 are not distinguished individually, any one of them may simply be referred to as a microwave generator 11. The same applies to other constituent elements. In this embodiment, in the configuration of the cavities 13 that are connected in series, the upstream side along the movement direction of fibers 3 may be referred to as an earlier-stage side, and the downstream side may be referred to as a later-stage side.

[0019] The carbonization apparatus 1 may further include, as necessary, at least one of an inlet portion 15 for the fibers 3, which is connected to the earliest-stage cavity 13-1, connection portions 16-1 and 16-2 that each connect two adjacent cavities 13, an outlet portion 17 for the fibers 3, which is connected to the last-stage cavity 13-3, temperature sensors 18-1, 18-2, and 18-3 that measure the respective temperatures of the structures 14, and a control unit 19 that controls the microwave generators 11 using the temperatures measured by the temperature sensors 18. The carbonization apparatus 1 may further include, as necessary, at least one of a discharge pipe 22 having a discharge port 21 at one end for discharging gas generated in the cavity 13, a supply pipe 24 having a supply port 23 at one end for supplying inert gas into the cavity 13, and a needle array circuit 25 for preventing propagation of microwaves at the inlet portion 15, the connection portion 16, and the outlet portion 17.

[0020] The carbonization apparatus 1 carbonizes precursor fibers of carbon fibers while continuously moving them inside the cavity 13. Accordingly, the fibers 3 introduced from the inlet portion 15 to the cavity 13-1 are precursor fibers after thermal stabilization, and the fibers 3 discharged from the outlet portion 17 are carbon fibers. As an example, the precursor fibers may be polyacrylonitrile (PAN). For convenience, thermally stabilized fibers, which are precursor fibers obtained by oxidation through thermal stabilization, are also referred to as precursor fibers. The fibers 3 may be, for example, a single fiber, but they are typically a fiber bundle in which a plurality of fibers are bundled. Accordingly, the fibers 3 may be, for example, a precursor

fiber bundle or a carbon fiber bundle.

[0021] The microwave generator 11 may generate microwaves, for example, using a magnetron, a klystron, a gyrotron, a semiconductor element, or the like. The generating microwaves using a semiconductor device may mean, for example, oscillating microwaves using a semiconductor device or amplifying microwaves using a semiconductor device. The frequency band of the microwaves may be, for example, in the vicinity of 433.92 MHz, 915 MHz, 2.45 GHz, or 5.8 GHz, or other frequency bands in the range of 300 MHz to 300 GHz. As will be described later, the two or more structures 14 are irradiated with microwaves such that a structure 14 on a later-stage side reaches a higher temperature. Accordingly, the output (power) of the plurality of microwave generators 11 may increase in the order of the microwave generators 11-1, 11-2, and 11-3.

[0022] The waveguide 12 guides the microwaves generated by the microwave generator 11 into the cavity 13. The waveguide 12 may be, for example, a rectangular waveguide or a circular waveguide. The waveguide 12 may be, for example, a hollow waveguide. For example, a microwave-transmissive airtight window may be provided, for example, at an end or another portion of the waveguide 12 to prevent gas or the like from the cavity 13 from moving toward the microwave generator 11. The airtight window may be made of, for example, a microwave-transmissive material. The microwave-transmissive material is not particularly limited, but examples thereof may include quartz glass, a fluororesin such as polytetrafluoroethylene, and a ceramic. For example, instead of the waveguide 12, a microwave guide unit such as a coaxial cable may be used to guide the microwaves. The interior of the cavity 13 may be directly irradiated with microwaves generated by the microwave generator 11. In this case, for example, the carbonization apparatus 1 does not have to include the waveguide 12, and an antenna for emitting microwaves may be provided in the cavity 13.

[0023] The microwaves generated by the microwave generator 11 are introduced into the cavity 13. The shape of the internal space of the cavity 13 is not particularly limited, but examples thereof may include a pillar-like shape extending in one direction. The one direction may be, for example, the movement direction of the fibers 3. The pillar-like shape may be, for example, a rectangular parallelepiped shape or a solid cylindrical shape. In this embodiment, a case will be mainly described in which the internal space of the cavity 13 has a rectangular parallelepiped shape.

[0024] The cavity 13 preferably has a wall made of a material that does not transmit microwaves so as to prevent leakage of microwaves from the internal space. The material that does not transmit microwaves may be, for example, a microwave-reflective material. The microwave-reflective material is not particularly limited, but examples thereof may include a metal such as

stainless steel, carbon steel, nickel, a nickel alloy, copper, and a copper alloy.

[0025] The plurality of cavities 13 are connected in series. The plurality of cavities 13 being connected in series may mean that the plurality of cavities 13 are connected such that the fibers 3 moving inside the plurality of cavities 13 pass through the cavities sequentially. The plurality of cavities 13 may be connected in series, for example, via the connection portion 16. Each cavity 13 may have, for example, an introduction port through which the fibers 3 are introduced into the internal space and a discharge port through which the fibers 3 are discharged from the internal space. Microwave irradiation within each cavity 13 is typically performed in a multi-mode manner. When carbonization is performed, the interior of each cavity 13 is typically at atmospheric pressure.

[0026] In this embodiment, a case will be mainly described in which the number of microwave generators 11 is equal to the number of cavities 13 and microwaves generated by the two or more microwave generators 11 are respectively introduced into the two or more cavities 13, but there is no limitation to this. For example, microwaves generated by two or more microwave generators 11 may be introduced into one cavity 13, or microwaves generated by one microwave generator 11 may be branched and introduced into two or more cavities 13.

[0027] Two or more structures 14 each having a hollow pillar-like shape (hollow pillar-like structures) are arranged in series within the two or more cavities 13. Each hollow pillar-like structure 14 may have, for example, a straight elongated shape. A cross-sectional shape in a plane perpendicular to a longitudinal direction of the hollow pillar-like structure 14 may be, for example, rectangular or another shape. Openings communicating with the hollow portion of the hollow pillar-like structure 14 are provided at both longitudinal ends of the structure 14. In this embodiment, a case will be mainly described in which the cross-sectional shape of the hollow pillar-like structure 14 is rectangular, that is, the structure 14 has a rectangular tube shape. The two or more structures 14 may be arranged in series as a result of the two or more structures 14 being respectively arranged within the two or more cavities 13, and the two or more cavities 13 being connected in series. In this embodiment, a case will be mainly described in which the number of cavities 13 is equal to the number of structures 14 and one structure 14 is arranged in one cavity 13, but there is no limitation to this. As will be described later, the two or more structures 14 may be arranged in one cavity 13.

[0028] FIG. 3A is a perspective view showing an external appearance of the structure 14, and FIGS. 3B and 3C are longitudinal cross-sectional views of the cavity 13 and the structure 14. FIG. 3B is a longitudinal cross-sectional view at a position where a frame member 31 is not present, and FIG. 3C is a longitudinal

cross-sectional view at a position where the frame member 31 is present. As shown in FIGS. 3A, 3B, and 3C, the plurality of fibers 3 arranged in parallel may move inside the structure 14. As shown in FIG. 3B, for example, a cross section in a plane perpendicular to a longitudinal direction of the structure 14 may be rectangular, and the plurality of fibers 3 may be arranged along a long side thereof. The distances between inner walls of the structure 14 and the plurality of fibers 3 are preferably equivalent. For example, as shown in FIGS. 3B and 3C, distances between two inner walls of the structure 14 facing each other and the fibers 3 may be equivalent. The distance is preferably such that heat exchange between the inner walls of the structure 14 and the plurality of fibers 3 can occur. As shown in FIGS. 3A, 3B, and 3C, the plurality of fibers 3 may be arranged in parallel such that a plurality of fibers 3 lie in the same plane. In this case, spacing between the plurality of fibers 3 may be, for example, uniform. The plurality of fibers 3 typically move at the same speed in the longitudinal direction of the fibers 3.

[0029] The structure 14 partially absorbs microwaves introduced from the outside, and partially transmits the microwaves inward. The structure 14 preferably has microwave transmittance such that a temperature difference between the structure 14 and the fibers 3 becomes small, by heating the structure 14 with microwaves absorbed by the structure 14 and heating the fibers 3 with microwaves transmitted through the structure 14. If the entire outer peripheral surface of the structure 14 is irradiated with microwaves as shown in FIG. 3B, multi-mode microwave irradiation within the cavity 13 allows the structure 14 to be heated more uniformly. The plurality of fibers 3 are also more uniformly heated with microwaves transmitted through the wall surface of the structure 14. At least one structure 14 of the plurality of structures may be irradiated with microwaves such that, for example, the structure 14 reaches a temperature equivalent to a target temperature of the plurality of fibers 3 moving inside the structure 14. Since thermally stabilized fibers at room temperature or thermally stabilized fibers immediately after thermal stabilization treatment are introduced into the earliest-stage cavity 13-1, a temperature difference between the fibers 3 and the earliest-stage structure 14-1 in an upstream region in the structure 14-1 is larger than that in the other regions in the structures 14. In the other regions, the fibers 3 and the structure 14 can be irradiated with microwaves such that a temperature difference therebetween becomes small.

[0030] The microwave transmittance of the structure 14 is not particularly limited, but, for example, at a carbonization temperature, about 20% to 80% of microwaves may be transmitted from the outside to the inside, and about 30% to 50% of microwaves may be transmitted from the outside to the inside. As carbonization proceeds, the fibers 3 exhibit increased microwave absorption, and the fibers 3 themselves generate

more heat. Therefore, a structure 14 on a later-stage side may have a lower microwave transmittance. The transmittance of the structure 14 may decrease, for example, in the order of the structures 14-1, 14-2, and 14-3. The microwave transmittance can be adjusted, for example, by changing at least one of the material of the structure 14 and the wall thickness of the structure 14.

[0031] In the carbonization, the temperature of the fibers 3 is gradually increased. For example, at the start of the carbonization, the temperature of the fibers 3 is about 300°C to 500°C, whereas at the end of the carbonization, the temperature of the fibers 3 reaches 1000°C or higher, such as 1100°C to 1200°C. Accordingly, two or more structures 14 are preferably irradiated with microwaves such that a structure 14 on a later-stage side along the movement direction of the plurality of fibers 3 reaches a higher temperature. In the example shown in FIG. 2, the structures 14 may be irradiated with microwaves such that the temperature increases in the order of the structures 14-1, 14-2, and 14-3. For example, the structure 14-1 may be heated to 500°C, and the structure 14-3 may be heated to 1100°C.

[0032] The material of the structure 14 is not particularly limited as long as it partially absorbs microwaves and partially transmits the microwaves, but examples thereof may include a material containing alumina or silicon nitride. As an example, the structure 14 may be made of sialon (SiAlON) containing silicon nitride. A structure 14 containing silicon nitride has improved heat resistance. Accordingly, a structure 14 on a later-stage side, in particular, the last-stage structure 14-3 preferably contains silicon nitride. Meanwhile, a structure 14 on an earlier-stage side in which the temperature does not become high preferably contains alumina, which is less expensive than silicon nitride. For example, the structures 14-1 and 14-2 may be made of alumina, and the structure 14-3 may be made of silicon nitride.

[0033] The structure 14 may be supported within the internal space of the cavity 13 by a predetermined support unit or the like. For example, as shown in FIG. 3B, in the internal space of the cavity 13, the support unit may include a pair of protrusions 32 that are respectively provided on a pair of inner walls of the cavity facing each other in the arrangement direction of the plurality of fibers 3, and a plate-like member 33 whose ends are supported by the pair of protrusions 32. The structure 14 may be placed, for example, on an upper surface of the plate-like member 33. The pair of protrusions 32 may be, for example, metal members extending along the movement direction of the fibers 3. The plate-like member 33 may be made of, for example, a microwave-transmissive or thermally-insulating material. The microwave-transmissive and thermally-insulating plate-like member 33 may be made of, for example, a material containing alumina.

[0034] The structure 14 may be arranged in the internal space of the cavity 13, for example, so as to connect an introduction port of the cavity 13 and a discharge port of the cavity 13. That is to say, the fibers 3 introduced from the introduction port of the cavity 13 into the internal space may move inside the structure 14 and be discharged from the discharge port of the cavity 13. The structure 14 expands thermally when heated with microwaves. If the degree of thermal expansion is larger than that of the cavity 13, as shown in FIG. 2, the longitudinal length of the structure 14 may be shorter than the length of the internal space of the cavity 13 along the movement direction of the fibers 3 by an amount corresponding to the thermal expansion. If gas generated by the heating of the organic fibers 3 flows out of the structure 14, the gas condenses on the inner walls of the cavity 13 to form tar, which needs to be removed. The reason for this is that tar absorbs microwaves. If a gap exists between the introduction port or discharge port of the cavity 13 and the corresponding end of the structure 14, gas generated by the heating of the fibers 3 may flow out of the structure 14 through that gap. Therefore, as shown in FIGS. 2 and 3C, a frame member 31 may be provided on the inner walls of the cavity 13 to surround the introduction port and the discharge port. Furthermore, the outer peripheral surfaces of both longitudinal ends of the structure 14 may be surrounded by the frame member 31. The frame member 31 may be made of, for example, a metal. Since the frame member 31 and the structure 14 are not fixed, the structure 14 can thermally expand along the inner peripheral surface of the frame member 31 when the structure reaches a high temperature. In this manner, if both longitudinal ends of the structure 14 are surrounded by the frame member 31, it is possible to prevent gas generated by the heating of the fibers 3 from flowing out of the structure 14. If one structure 14 is arranged in one cavity 13 as shown in FIG. 2, both ends of the structure 14 may be supported by the frame member 31 on the introduction port side and the frame member 31 on the discharge port side. In this case, the protrusions 32 and the plate-like member 33 may not be present in the internal space of the cavity 13.

[0035] If two or more structures 14 are arranged in series in the internal space of one cavity 13, two adjacent structures 14 are preferably arranged such that no gap exists therebetween. Cross sections at connection portion may have the same shape. In this manner, by ensuring that the space inside the structure 14 and the space outside the structure 14 do not communicate in the internal space of the cavity 13, it is possible to prevent gas generated by the heating of the organic fibers 3 from flowing to the space outside the structure 14. As a result, the space outside the structure 14 in the internal space of the cavity 13 can be kept free from contamination by gas, thereby reducing the workload associated with cleaning that space. In this embodiment, since the structure 14 is also heated, it is possible to

prevent gas generated by the heating of the fibers 3 from condensing on the inner walls of the structure 14 and forming tar. Consequently, tasks such as tar removal become unnecessary.

[0036] The length of the cavity 13 and the structure 14 in the direction along the fibers 3, the respective temperatures of the two or more structures 14, the movement speed of the fibers 3, and the like are preferably determined as appropriate so that the desired carbonization is performed within the cavity 13. The dielectric constant of the structure 14 and the output of the microwave generator 11 that generates microwaves for use in irradiation of the structure 14 are preferably determined as appropriate so that the structure 14 can be heated to the desired temperature.

[0037] Hereinafter, effects of heating not only the fibers 3 but also the structures 14 with microwaves will be described. If only the fibers are directly heated with microwaves, ambient temperature becomes lower than the fiber temperature, causing cooling of the fiber surface and resulting in temperature non-uniformity between the inside and surface of the fibers. Furthermore, when a plurality of fibers are arranged in parallel, that is, moved in parallel, heating non-uniformity also occurs among the plurality of fibers. The reason for this is that it is difficult to irradiate a plurality of fibers with microwaves uniformly. On the other hand, when the fibers 3 are moved inside the structures 14 that are heated with microwaves, the ambient temperature in a structure 14 on a later-stage side can be made comparable to that of the fibers 3, thereby reducing temperature non-uniformity between the inside and surface of the fibers 3. If each structure 14 is made of, for example, a material having thermal conductivity comparable to or higher than that of alumina or silicon nitride, the entire structure 14 attains a uniform temperature. Therefore, heat exchange between the plurality of fibers 3 and the inner walls of the structure 14 occurs, and thus the temperature of the plurality of fibers 3 is made comparable to that of the structure 14, thereby reducing heating non-uniformity among the plurality of fibers 3. In this manner, more uniform heating of the plurality of fibers 3 can be achieved, enabling the production of more homogeneous carbon fibers.

[0038] The inlet portion 15 is a hollow pillar-like member having one end connected to the introduction port for the fibers 3 in the earliest-stage cavity 13-1. The fibers 3 are introduced into the carbonization apparatus 1 from the opening at the inlet portion 15's end that is not connected to the cavity 13-1, and are subjected to carbonization.

[0039] The connection portion 16 is a hollow pillar-like member that connects two adjacent cavities 13 among the two or more cavities 13. An opening at one end is connected to the discharge port for the fibers 3 in the cavity 13 on the earlier-stage side, and an opening at the other end is connected to the introduction port for the fibers 3 in the cavity 13 on the later-stage side.

Since the fibers 3 are not heated in the connection portion 16, the length of the connection portion 16 in the direction along the fibers 3 is preferably short.

[0040] The outlet portion 17 is a hollow pillar-like member having one end connected to the discharge port for the fibers 3 in the last-stage cavity 13-3. The fibers 3 after carbonization, that is, carbon fibers are discharged from the opening at the outlet portion 17's end that is not connected to the last-stage cavity 13-3.

[0041] Cross-sectional shapes of the inlet portion 15, the connection portion 16, and the outlet portion 17 in a plane perpendicular to a longitudinal direction of the fibers 3 may be, for example, rectangular. The inlet portion 15, the connection portion 16, and the outlet portion 17 are preferably made of materials that do not transmit microwaves. Each of the inlet portion 15, the connection portion 16, and the outlet portion 17 is preferably connected to the cavity 13 such that microwaves do not leak from each connection portion.

[0042] For example, the temperature sensor 18 may measure the temperature of the structure 14 arranged in the cavity 13. The temperature sensor 18 may be, for example, a radiation thermometer that measures the temperature of an outer peripheral surface of the structure 14. In this embodiment, a case will be mainly described in which the temperature of one structure 14 is measured by one temperature sensor, but the temperature of one structure 14 may be measured by two or more temperature sensors 18. In this case, for example, a representative value of two or more temperatures measured by the two or more temperature sensors 18 may be adopted as the temperature of the structure 14. The representative value may be, for example, an average value, a median value, a maximum value, or a minimum value.

[0043] The control unit 19 may control the microwave generators 11, for example, using the temperatures measured by the temperature sensors 18. The control unit 19 may control the microwave generators 11 that generate microwaves introduced into the cavities 13 in which the structures 14 are arranged such that the structures 14 reach desired temperatures. More specifically, the control unit 19 may control the microwave generator 11-1 such that the structure 14-1 reaches a desired temperature. This control may be feedback control. As an example, the control unit 19 may perform control such that the temperature of the structure 14 reaches a temperature equivalent to a target temperature of the plurality of fibers 3 moving inside the structure 14. The term "equivalent temperature" may refer to, for example, the same temperature, or a temperature close enough to be considered substantially the same. In the latter case as well, it is preferable that the temperature of the structure 14 is close enough to the target temperature to reduce temperature non-uniformity within a single fiber 3 and reduce temperature differences among the plurality of fibers 3. As described above, the temperature of the fibers 3 is gradually in-

creased in the carbonization, and thus the control unit 19 may control the microwave generators 11-1, 11-2, and 11-3 such that the temperature increases in the order of the structures 14-1, 14-2, and 14-3, that is, such that a structure 14 on a later-stage side reaches a higher temperature.

[0044] Furthermore, at least one of the connection portions 16-1 and 16-2 and the outlet portion 17 may be provided, for example, with a discharge port 21 for discharging gas generated by the heating of the fibers 3 in the cavity 13 on the earlier-stage side. The discharge port 21 may be, for example, at one end of the discharge pipe 22. In this manner, the interiors of the structure 14, the connection portion 16, and the outlet portion 17 can be kept free from contamination by discharging gas generated in the cavity 13 from the discharge port 21 and the discharge pipe 22 provided between adjacent cavities 13 among the two or more cavities 13 or provided at the outlet portion 17 for the fibers 3 in the last-stage cavity 13-3. As an example, the connection portions 16-1 and 16-2 and the outlet portion 17 may be provided with two or more discharge ports 21 and discharge pipes 22 along the arrangement direction of the plurality of fibers 3. The diameter of the discharge port 21 and the length of the discharge pipe 22 may be determined so as to prevent leakage of microwaves via the discharge pipe 22. As an example, the diameter of the discharge port 21 may be one-quarter or less of the wavelength of the microwaves for use in irradiation in the cavity 13.

[0045] Furthermore, at least one of the inlet portion 15 and the connection portions 16-1 and 16-2 may be provided, for example, with a supply port 23 for supplying inert gas into the cavity 13 on the later-stage side. The supply port 23 may be, for example, at one end of the supply pipe 24. In this manner, the fibers 3 can be heated in an inert atmosphere by supplying inert gas into the cavity 13 from the supply pipe 24 and the supply port 23 provided at the inlet portion 15 for the fibers 3 in the earliest-stage cavity 13-1 or provided between adjacent cavities 13 among the two or more cavities 13. The inert gas is not particularly limited, but examples thereof may include nitrogen and argon. The position of the supply port 23 and the flow rate and orientation of inert gas supplied from the supply port 23 may be determined as appropriate by simulation or the like so that the inert gas is effectively supplied into the cavity 13. As an example, the inlet portion 15 and the connection portions 16-1 and 16-2 may be provided with two or more supply ports 23 and supply pipes 24 along the arrangement direction of the plurality of fibers 3. The diameter of the supply port 23 and the length of the supply pipe 24 may be determined so as to prevent leakage of microwaves via the supply pipe 24. As an example, the diameter of the supply port 23 may be one-quarter or less of the wavelength of the microwaves for use in irradiation.

[0046] The inlet portion 15, the connection portion

16, and the outlet portion 17 may be provided, for example, with a needle array circuit 25 for preventing propagation of microwaves. The needle array circuit 25 may be referred to as a needle array structure. FIG. 4A is a longitudinal cross-sectional view of the connection portion 16 showing the needle array circuit 25, and FIG. 4B is a transverse cross-sectional view of the connection portion 16 showing the needle array circuit 25. FIG. 4B is a transverse cross-sectional view taken along a plane passing through needle-like members 26. The needle array circuit 25 may have a plurality of needle-like members 26 arranged in parallel. The longitudinal length of each needle-like member 26 may be, for example, one-quarter of the wavelength of the microwaves for use in irradiation in the cavity 13. The needle-like members 26 are preferably made of, for example, a conductive material. The conductive material may be, for example, a metal. The metal is not particularly limited, but examples thereof may include stainless steel, carbon steel, nickel, a nickel alloy, copper, and a copper alloy. The plurality of needle-like members 26 are preferably arranged in the inlet portion 15, the connection portion 16, and the outlet portion 17 so as not to obstruct movement of the fibers 3 and so as to prevent propagation of microwaves. In this embodiment, a case is shown in which the needle array circuit 25 is provided on upper inner walls of the inlet portion 15, the connection portion 16, and the outlet portion 17, but the needle array circuit 25 may be provided on lower inner walls. However, the needle array circuit 25 is preferably provided on upper inner walls in order to prevent the fibers 30 from being caught on the needle array circuit 25 when the fibers 30 are threaded through the inlet portion 15, the connection portion 16, and the outlet portion 17. In this manner, if the needle array circuit 25 is provided between adjacent cavities 13 among the two or more cavities 13, the propagation of microwaves between the cavities 13 can be prevented, and it becomes easier to control the temperature of the structure 14 in each cavity 13. If the inlet portion 15 and the outlet portion 17 are provided with the needle array circuit 25, the leakage of microwaves to the outside of the carbonization apparatus 1 via the inlet portion 15 and the outlet portion 17 can be prevented.

[0047] Since the carbonization is completed in the last-stage cavity 13-3, the fibers 3 discharged from the last-stage cavity 13-3 are carbon fibers formed by the carbonization of the precursor fibers and exhibit high electrical conductivity. Therefore, there is a possibility that microwaves may leak to the outside via the conductive fibers 3 discharged from the last-stage cavity 13-3. In order to prevent such leakage of microwaves, the carbonization apparatus 1 may further include, for example, an electrical conduction unit that electrically interconnects the plurality of fibers 3 in the vicinity of the discharge port for the plurality of fibers 3 in the last-stage cavity 13-3. The electrical conduction unit may be provided, for example, in the outlet portion 17.

In this manner, the plurality of carbon fibers are electrically interconnected, and thus the potential difference therebetween is eliminated. As a result, the generation of an electromagnetic field between the plurality of carbon fibers can be prevented, thereby preventing radiation of microwaves from the carbon fibers into the surrounding space.

[0048] As an example, the electrical conduction unit may be a roller 27 shown in FIG. 5. For example, the roller 27 may be arranged in the outlet portion 17 so as to be rotatable, and may be rotated by a drive unit such as a motor in accordance with the movement speed of the fibers 3. The outer peripheral surface of the roller 27 is preferably made of a conductive material. The conductive material may be, for example, a metal. In the outlet portion 17, the roller 27 is preferably arranged such that the direction of its rotational axis is perpendicular to the longitudinal direction of the plurality of fibers 3 and such that the plurality of fibers 3 come into contact with its outer peripheral surface. For example, the roller 27 may be grounded.

[0049] FIG. 5 shows a case in which the roller 27 is arranged closer to the discharge port of the last-stage cavity 13-3 than the needle array circuit 25 is, but the roller 27 may be arranged at a different position. For example, in FIG. 5, the roller 27 may be arranged in the vicinity of the needle array circuit 25, or may be arranged closer to the opening on the downstream side of the outlet portion 17 than the needle array circuit 25 is. For example, the roller 27 may be arranged above the plurality of fibers 3. The plurality of fibers 3 may be electrically interconnected by a unit other than the roller 27.

[0050] Next, a method for producing carbon fibers using the carbonization apparatus 1 according to this embodiment will be described. The fibers 3 to be subjected to carbonization are thermally stabilized fibers, and, for example, they may be supplied directly from a thermal stabilization apparatus to the carbonization apparatus 1 or unwound from a spool or the like and supplied to the carbonization apparatus 1. In the former case, the fibers 3 at about 250°C are supplied to the carbonization apparatus 1, and in the latter case, the fibers 3 at room temperature are supplied to the carbonization apparatus 1. The plurality of fibers 3 are moved in a state arranged in parallel, for example, as indicated by the arrows in FIGS. 1 and 2. The plurality of fibers 3 may be moved, for example, by being wound up by a winding unit downstream of the outlet portion 17. The plurality of fibers 3 are preferably moved, for example, at a predetermined speed, such as 5 meters per minute.

[0051] The interior of each cavity 13 is irradiated with microwaves such that the structure 14 reaches a desired temperature. As described above, the structures 14 are preferably irradiated with microwaves such that a structure on a later-stage side reaches a higher temperature. This microwave irradiation may be performed

by adjusting the output of the microwave generators 11 using the temperatures measured by the temperature sensors 18. During the carbonization, the plurality of fibers 3 are heated in an inert atmosphere by supplying inert gas such as nitrogen into the cavity 13 via the supply pipe 24. Gas generated by the heating of the plurality of fibers 3 is discharged from the discharge pipe 22. Since the inlet portion 15, the connection portion 16, and the outlet portion 17 are provided with the needle array circuit 25, the leakage of microwaves at the inlet portion 15 and the outlet portion 17 can be prevented, and the propagation of microwaves between the cavities 13 can be prevented as well. In this manner, carbon fibers can be manufactured by continuously heating and carbonizing a plurality of precursor fibers.

[0052] As described above, with the carbonization apparatus 1 according to this embodiment, since the plurality of fibers 3 are simultaneously carbonized, it is possible to commercially produce carbon fibers. In the case of performing the carbonization using a plurality of cavities 13, the temperature of the structure 14 within each cavity 13 can be controlled independently, making it easy to perform control such that the structure 14 reaches a desired temperature.

[0053] Furthermore, since the structure 14 partially absorbs microwaves introduced from the outside and partially transmits the microwaves, the temperature of the fibers 3 inside the structure 14 can be made comparable to that of the structure 14. As a result, the temperature difference between the surface of the fibers 3 and the inside of the fibers 3 can be reduced, thereby reducing temperature non-uniformity in a single fiber 3, in the strict sense, in a single fiber bundle. If the structure 14 is mainly made of, for example, alumina or silicon nitride, its high thermal conductivity ensures that the entire structure 14 is heated to a more uniform temperature. Therefore, heat exchange between the plurality of fibers 3 that are present inside the structure 14 and the inner walls of the structure 14 occurs, and thus the temperature difference among the plurality of fibers 3 can be reduced, thereby reducing heating non-uniformity among the plurality of fibers 3. This configuration enables the production of more homogeneous carbon fibers.

[0054] Furthermore, since microwave irradiation within the cavity 13 is performed in a multi-mode manner, the size of the structure 14 is not limited as in single-mode irradiation. Accordingly, by making the structure 14 larger, it becomes possible to arrange a larger number of fibers 3 in parallel and carbonize them collectively. In this case as well, as described above, the temperature non-uniformity within a fiber bundle and the heating non-uniformity among a plurality of fiber bundles are small, and thus it is possible to mass-produce homogeneous carbon fibers.

[0055] Furthermore, if gas generated by the heating of the fibers 3 is discharged from the discharge port 21

provided at the connection portion 16 and the outlet portion 17, the inner walls of the structure 14 and the like can be kept free from contamination by that gas. In particular, if the discharge port 21 is provided at the connection portion 16, it becomes possible to discharge gas generated by the heating of the fibers 3 even during intermediate stages of the heating of the fibers 3. Since the structure 14 itself is also heated with microwaves, it is possible to prevent tar and the like from condensing on the inner walls of the structure 14.

[0056] Furthermore, since inert gas is supplied into the cavity 13 from the supply port 23 provided at the inlet portion 15 and the connection portion 16, carbonization can be performed in an inert atmosphere. If the gas generated by the heating of the fibers 3 is discharged and the inert gas is supplied at the connection portion 16, the atmospheric gas can be replaced with clean inert gas during the intermediate stages of the heating of the fibers 3.

[0057] Furthermore, since the inlet portion 15, the connection portion 16, and the outlet portion 17 are provided with the needle array circuit 25, the leakage of microwaves to the outside via the inlet portion 15 and the outlet portion 17 can be prevented. Additionally, the propagation of microwaves via the connection portion 16 can be prevented as well, making it easier to control the temperature of the structure 14 in each cavity 13.

[0058] Furthermore, when a plurality of carbon fibers are discharged from the last-stage cavity 13-3, the plurality of carbon fibers are electrically interconnected using an electrical conduction unit such as the roller 27, and thus the leakage of microwaves to the outside via the plurality of carbon fibers can be prevented.

[0059] In this embodiment, the case was mainly described in which three cavities 13 and three structures 14 are provided, but it will be appreciated that the number of cavities 13 and structures 14 need not be limited to three. For example, the number of cavities 13 and structures 14 included in the carbonization apparatus 1 may be two or four or more. A larger number of cavities 13 and structures 14 can realize a more finely controlled, stepwise increase in the temperature of the fibers 3, and thus from this perspective, a larger number of cavities 13 and structures 14 is preferable. For example, the number of cavities 13 and the number of structures 14 may be each three or more. Furthermore, the carbonization apparatus 1 preferably includes, for example, one or more microwave generators 11 and one or more waveguides 12 for each cavity 13.

[0060] Furthermore, in this embodiment, the case was mainly described in which one structure 14 is arranged in one cavity 13, but there is no limitation to this. For example, two or more structures 14 may be arranged in one cavity 13. FIG. 6 is a schematic longitudinal cross-sectional view showing an example of the carbonization apparatus 1 in which three structures 14-1, 14-2, and 14-3 connected in series are arranged in one cavity 13. In the carbonization apparatus 1

shown in FIG. 6 as well, the temperatures of the structures 14-1, 14-2, and 14-3 may be respectively measured by the temperature sensors 18, and the microwave generators 11-1, 11-2, and 11-3 may be controlled using the measured temperatures such that the structures 14-1, 14-2, and 14-3 each reach a desired temperature. It is assumed that in the carbonization apparatus 1 shown in FIG. 6, the outer peripheral surfaces of the structures 14-1, 14-2, and 14-3 are mainly irradiated inside the cavity 13 respectively with the microwaves generated by the microwave generators 11-1, 11-2, and 11-3. With this configuration, microwave irradiation can be performed such that the temperatures of the plurality of fibers 3 increase in a stepwise manner. Even when carbonization of precursor fibers is performed using one cavity 13 as shown in FIG. 6, microwaves are preferably generated by two or more microwave generators 11.

[0061] If two or more structures 14 are arranged in one cavity 13 as shown in FIG. 6, the connection portion between two adjacent structures 14 may be configured as an expansion joint structure to accommodate the longitudinal thermal expansion of each structure 14. FIG. 6 shows an example of an expansion joint structure. As shown in FIG. 6, the right end of the structure 14-1 may have an enlarged inner peripheral surface, while the left end of the structure 14-2 may have a reduced outer peripheral surface, and the left end of the structure 14-2 may be inserted into the right end of the structure 14-1.

[0062] Furthermore, the areas in the vicinity of the introduction port and the discharge port in the internal space of the cavity 13 are locations where temperature fluctuations may be significant, as they are connected to the outside via the introduction port and the discharge port of the cavity 13. Therefore, if three or more structures 14 are arranged in series in one cavity 13, the structure 14 on the introduction port side, that is, the earliest-stage structure 14 and the structure 14 on the discharge port side, that is, the last-stage structure 14 among the three or more structures 14 may be made of a material with high thermal shock resistance. Therefore, the structure 14 on the introduction port side and the last-stage structure 14 may contain, for example, silicon nitride.

[0063] Furthermore, in this embodiment, the case was mainly described in which the structure 14 has a hollow pillar-like shape, but there is no limitation to this. For example, as shown in FIG. 7, the structure 14 may have two plate-like members 14a and 14b arranged in parallel and facing each other. That is to say, the structure 14 may be a structure that does not include a face corresponding to the short side in the cross section of the structure 14 shown in FIG. 3B. The plate-like members 14a and 14b each partially absorb microwaves and partially transmit the microwaves. Accordingly, the plurality of fibers 3 moving inside the structure 14, that is, the plurality of fibers 3 moving between the two

plate-like members 14a and 14b are irradiated with microwaves transmitted through the two plate-like members 14a and 14b. In order to maintain a constant spacing between the two plate-like members 14a and 14b and to prevent gas generated by the heating of the fibers 3 from flowing out of the structure 14, a hollow pillar-like shape may be formed by two plate-like members 34 arranged in parallel and facing each other and the two plate-like members 14a and 14b. The plate-like members 34 may be made of, for example, a microwave-transmissive or thermally-insulating material. The microwave-transmissive and thermally-insulating plate-like members 34 may be made of, for example, a material containing alumina.

[0064] Furthermore, in this embodiment, the case was mainly described in which the internal space of the cavity 13 is irradiated with microwaves from the upper side, but there is no limitation on the direction from which the internal space of the cavity 13 is irradiated with microwaves. For example, the internal space of the cavity 13 may be irradiated with microwaves from the lower side, or may be irradiated with microwaves from both the upper side and the lower side. If the internal space of the cavity 13 is irradiated with microwaves from both the upper side and the lower side, for example, as shown in FIG. 8, the structure 14 may include two plate-like members 14a and 14b in which the length in the arrangement direction of the plurality of fibers 3 is equivalent to the length in the arrangement direction of the plurality of fibers 3 in the internal space of the cavity 13. In this case, as shown in FIG. 8, the plate-like members 14a and 14b may be respectively supported by the protrusions 32.

[0065] Furthermore, in the carbonization apparatus 1 according to this embodiment, a member that has a higher microwave transmittance than the structure 14 and a higher thermal insulation than the structure 14 may be provided so as to cover at least a portion of the outer surface of the structure 14, thereby reducing the transfer of heat from the structure 14 to the internal space of the cavity 13 without obstructing the microwave irradiation onto the structure 14. The member provided on the outer surface of the structure 14 may be arranged, for example, so as to cover all of the outer surface of the structure 14 having a hollow pillar-like shape shown in FIG. 3B, the outer surfaces of the structure 14 included in the hollow pillar-like shape shown in FIG. 7, and the outer surfaces of the structure 14 forming surfaces on the opposite side to the fibers 3 shown in FIG. 8, or so as to cover a portion of the outer surfaces. The shape of this member is not particularly limited, but examples thereof may include a plate-like shape. This member preferably has a lower specific heat capacity (heat storage capacity) per unit volume than the structure 14. For example, if the specific heat capacity per unit volume of the member provided on the outer surface of the structure 14 is larger than that of the structure 14, when lowering the temperature of

the structure 14, even if the microwave output is reduced, the temperature of the structure 14 will be difficult to lower due to the influence of that member. Furthermore, when starting microwave irradiation to raise the temperature of the structure 14, it will take longer to bring the temperature of the structure 14 to the desired temperature. On the other hand, such issues can be avoided by using a material with a lower specific heat capacity per unit volume than that of the structure 14. The member provided on the outer surface of the structure 14 may be constituted by, for example, a material formed by compacting alumina fibers. [0066] Furthermore, in this embodiment, the case was mainly described in which the movement direction of the plurality of fibers 3 is horizontal, but there is no limitation to this. The plurality of fibers 3 may be moved in directions other than the horizontal direction, such as the vertical direction. For example, when the plurality of fibers 3 are moved in the vertical direction, the plurality of fibers 3 are preferably moved upward from the lower side. The reason for this is that during the carbonization, the temperature of the fibers 3 has to be gradually increased, and gases at higher temperatures rise upward.

[0067] Furthermore, the foregoing embodiment is an example for specific implementation of the present invention and is not intended to limit the technical scope of the invention. The technical scope of the invention is indicated by the claims rather than by the foregoing description, and changes which come within the wording and equivalent meanings of the scope of the claims are intended to be encompassed therein.

Claims

1. A carbonization apparatus for carbonizing a plurality of precursor fibers of carbon fibers through heating, comprising:

two or more microwave generators that generate microwaves;
 one or two or more cavities into which microwaves generated by the two or more microwave generators are introduced; and
 two or more structures that are arranged in series within the one or two or more cavities and inside which the plurality of precursor fibers can move in parallel,
 wherein each of the two or more structures partially absorbs microwaves introduced from outside, and partially transmits the microwaves inward, and
 the two or more structures can be irradiated with microwaves such that a structure on a later-stage side along a movement direction of the plurality of precursor fibers reaches a higher temperature.

2. The carbonization apparatus according to claim 1, wherein at least one structure of the two or more structures can be irradiated with microwaves such that the structure reaches a temperature equivalent to a target temperature of the plurality of precursor fibers moving inside the structure.

3. The carbonization apparatus according to claim 1, wherein each of the two or more structures has a hollow pillar-like shape.

4. The carbonization apparatus according to any one of claims 1 to 3,

wherein the one or two or more cavities are two or more cavities connected in series, the microwaves generated by the two or more microwave generators are respectively introduced into the two or more cavities, and the two or more structures are respectively arranged within the two or more cavities.

5. The carbonization apparatus according to claim 4, wherein a discharge port is provided between adjacent cavities among the two or more cavities to discharge gas generated in an earlier-stage cavity of the adjacent cavities.

6. The carbonization apparatus according to claim 4, wherein a supply port is provided between adjacent cavities among the two or more cavities to supply inert gas into a later-stage cavity of the adjacent cavities.

7. The carbonization apparatus according to claim 4, wherein a needle array circuit is provided between adjacent cavities among the two or more cavities to prevent propagation of microwaves between the adjacent cavities.

8. The carbonization apparatus according to any one of claims 1 to 3, further comprising: an electrical conduction unit that electrically interconnects the carbon fibers in a vicinity of a discharge port of a last-stage cavity of the one or two or more cavities.

9. The carbonization apparatus according to any one of claims 1 to 3, wherein a last-stage structure of the two or more structures contains silicon nitride.

10. A method for producing carbon fibers by carbonizing a plurality of precursor fibers of carbon fibers through heating, comprising:

moving the plurality of precursor fibers in parallel inside two or more structures that are arranged in series within one or two or more cavities, each of the two or more structures par-

tially absorbing microwaves introduced from outside and partially transmitting the microwaves inward; and
irradiating the two or more structures with microwaves such that a structure on a later-stage side along a movement direction of the plurality of precursor fibers reaches a higher temperature.

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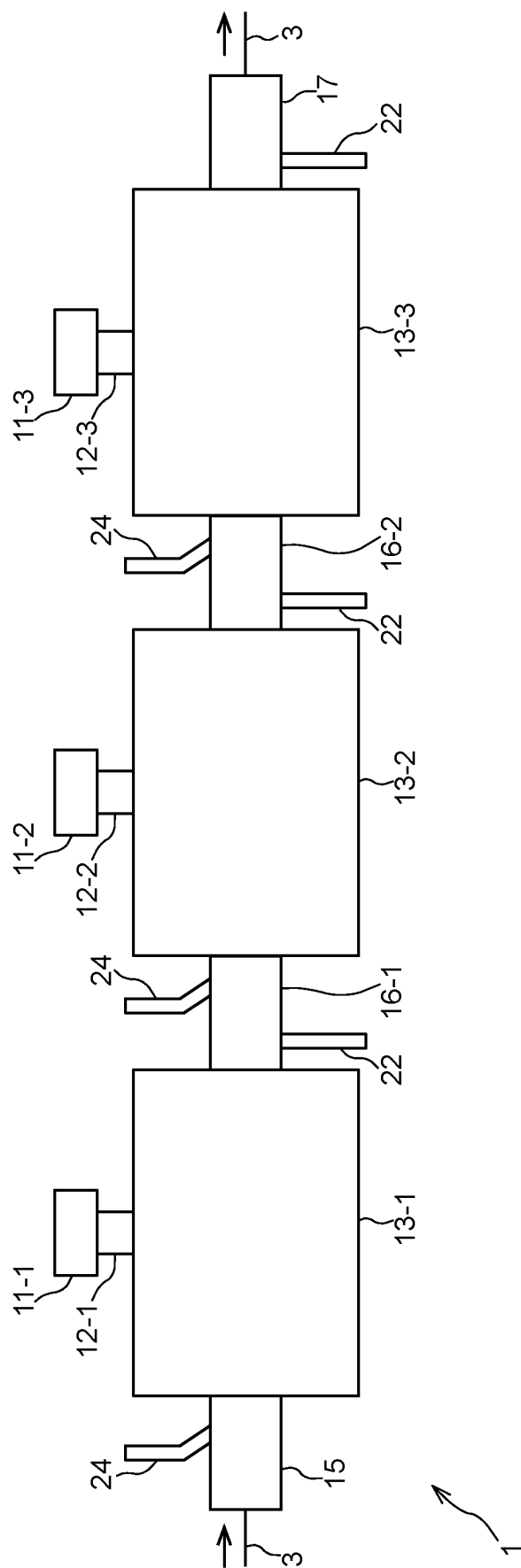


FIG. 1

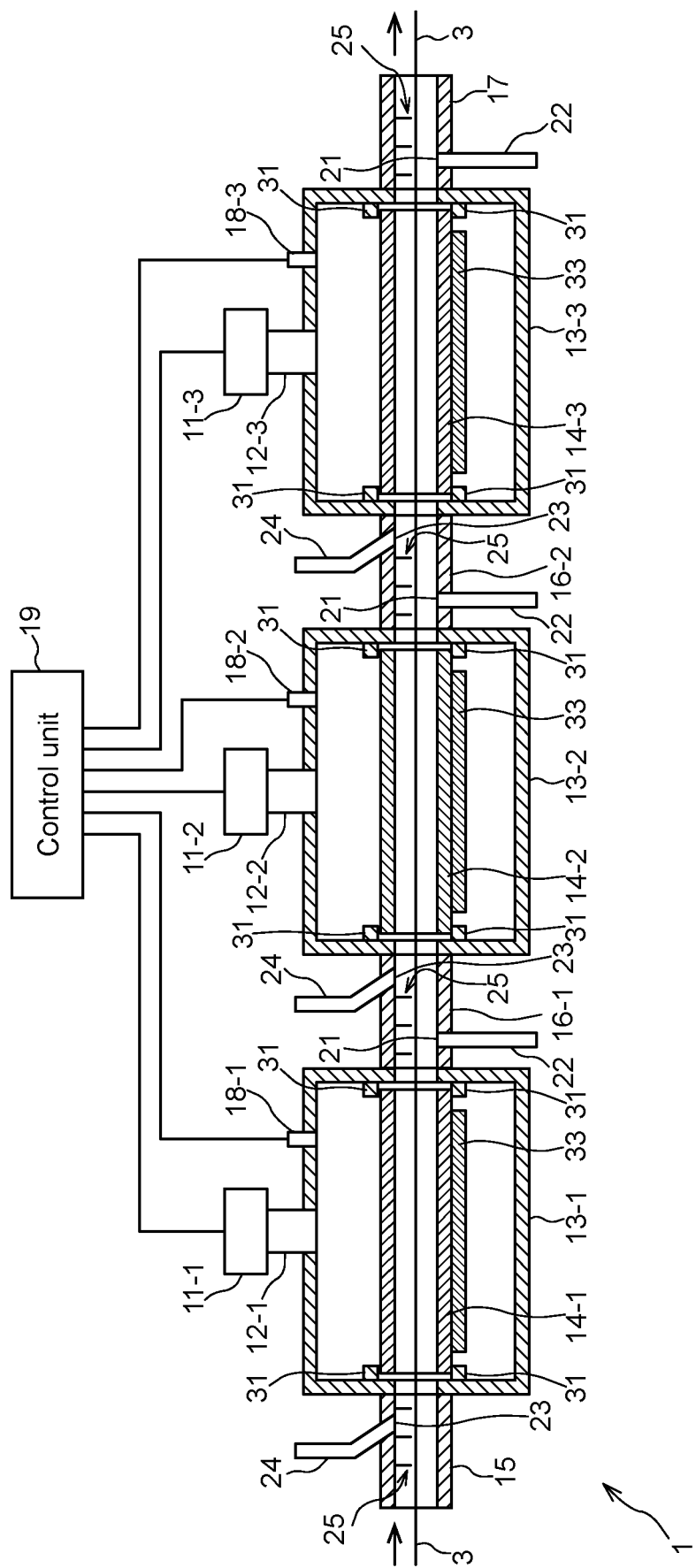


FIG. 2

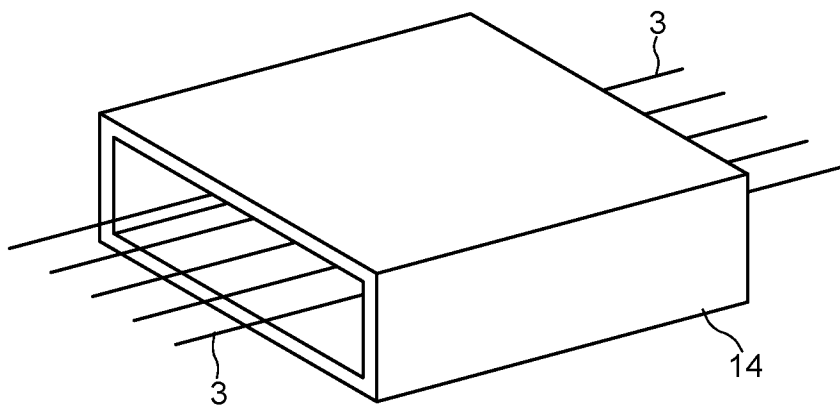


FIG. 3A

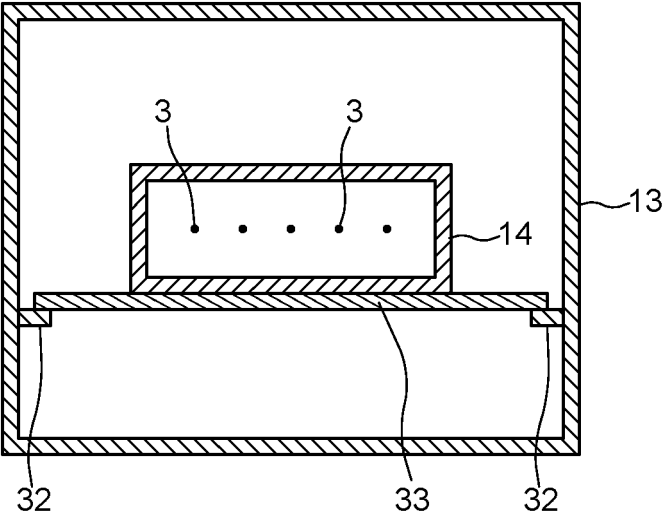


FIG. 3B

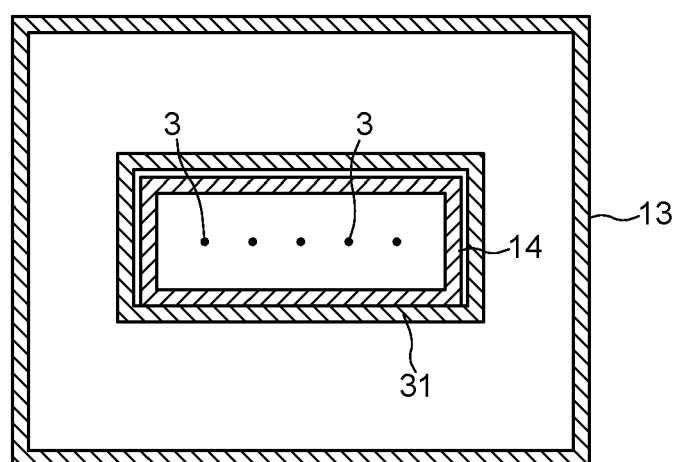


FIG. 3C

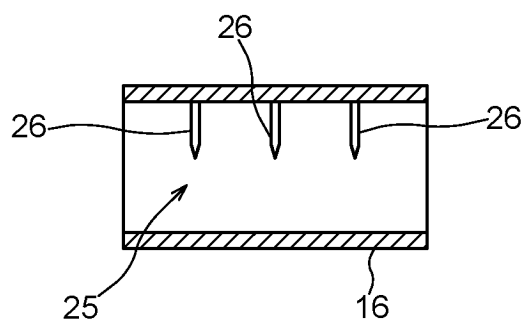


FIG. 4A

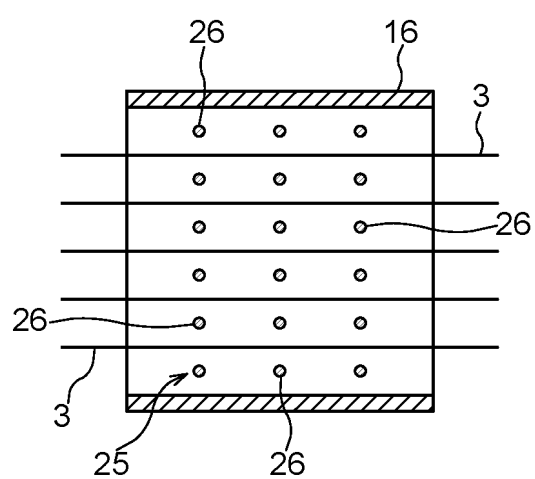


FIG. 4B

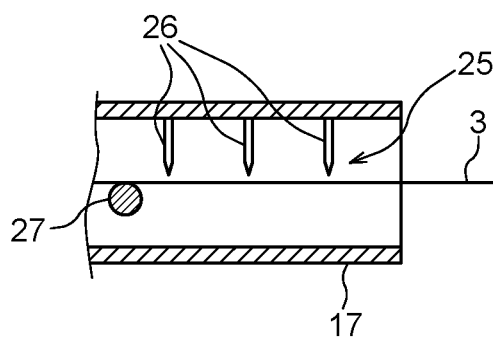


FIG. 5

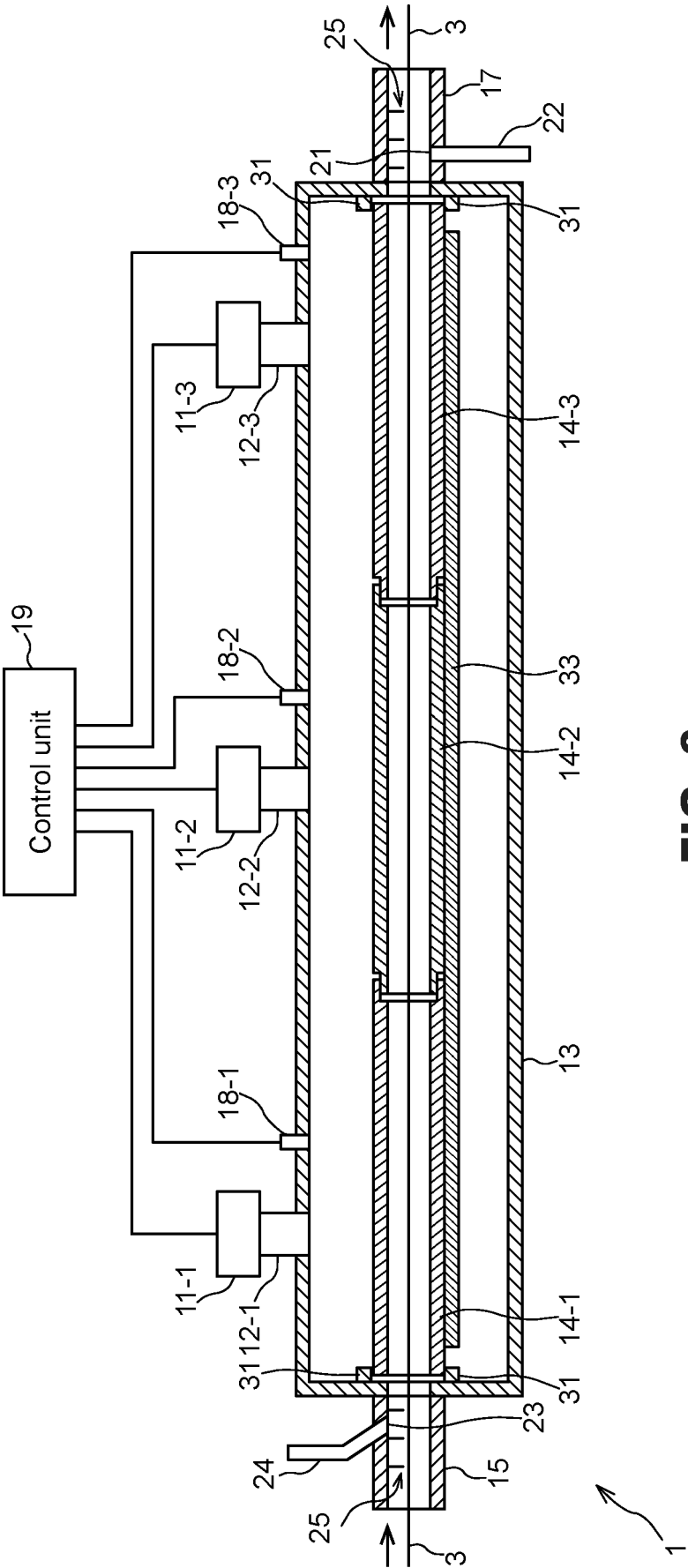


FIG. 6

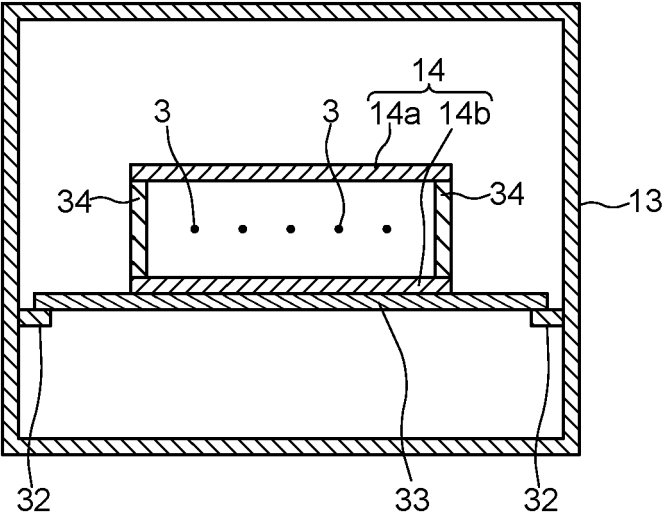


FIG. 7

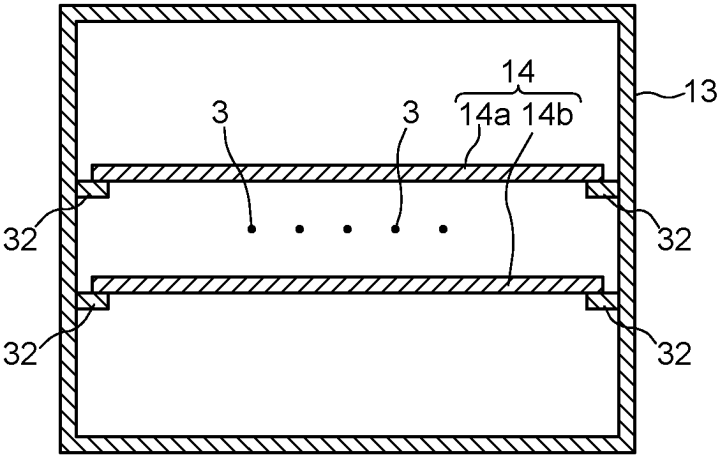


FIG. 8

INTERNATIONAL SEARCH REPORT

International application No.

PCT/JP2024/043521

A. CLASSIFICATION OF SUBJECT MATTER**D01F 9/32**(2006.01)i

FI: D01F9/32

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

D01F9/08-9/32; F27B9/00-9/40; F27D11/00-11/12; H05B6/64-6/80

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Published examined utility model applications of Japan 1922-1996

Published unexamined utility model applications of Japan 1971-2025

Registered utility model specifications of Japan 1996-2025

Published registered utility model applications of Japan 1994-2025

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	WO 2019/142578 A1 (MICROWAVE CHEMICAL CO., LTD.) 25 July 2019 (2019-07-25) claims, paragraph [0237], drawings	1-10
A	JP 2013-231244 A (APPLIED MATERIALS, INCORPORATED) 14 November 2013 (2013-11-14) paragraphs [0013]-[0024], drawings	1-10
A	JP 2013-2767 A (MICRO DENSHI CO., LTD.) 07 January 2013 (2013-01-07) paragraphs [0052]-[0078], drawings	1-10

☐ Further documents are listed in the continuation of Box C.☒ See patent family annex.

* Special categories of cited documents:

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“P” document published prior to the international filing date but later than the priority date claimed

“T” later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

“X” document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

“Y” document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

“&” document member of the same patent family

Date of the actual completion of the international search

18 February 2025

Date of mailing of the international search report

04 March 2025

Name and mailing address of the ISA/JP

Japan Patent Office (ISA/JP)

3-4-3 Kasumigaseki, Chiyoda-ku, Tokyo 100-8915

Japan

Authorized officer

Telephone No.

INTERNATIONAL SEARCH REPORT
Information on patent family members

International application No.
PCT/JP2024/043521

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				claims, paragraph [0240], figures			
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				JP	2020-98716	A	
				JP	2023-95923	A	
				JP	6446573	B1	
				US	2023/0137733	A1	
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				CN	117177398	A	
				TW	201932654	A	
				TW	202102055	A	
				TW	202418881	A	
				(Family: none)			
JP	2013-231244	A	14 November 2013	EP	2537966	A1	
JP	2013-2767	A	07 January 2013	paragraphs [0094]-[0142], figures			
				US	2013/0098904	A1	
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				BR	102012015109	A	
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