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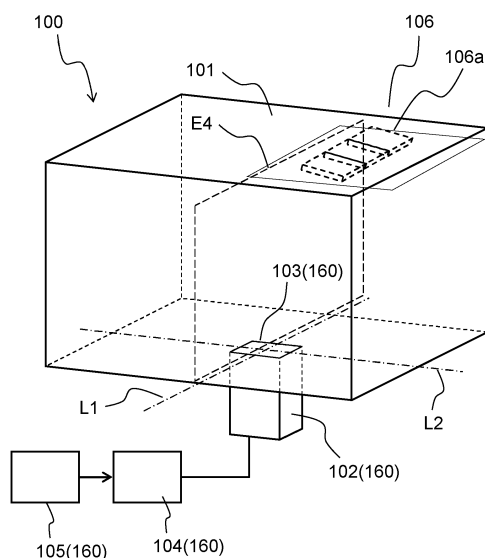
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(54) **MICROWAVE PROCESSING APPARATUS**

(57) A microwave treatment apparatus includes: a treatment chamber configured to accommodate a heating target; a microwave supply configured to supply microwaves to the treatment chamber; and a resonator unit having a resonance frequency in a frequency band of microwaves. The resonator unit includes a plurality of patch resonators disposed such that at least three patch resonators are arranged along an orientation of a polarization plane generated on a metal wall constituting the treatment chamber. According to an aspect, a standing wave distribution in the treatment chamber, that is, a microwave energy distribution, can be controlled.

FIG. 1



## Description

### TECHNICAL FIELD

[0001] The present disclosure relates to a microwave treatment apparatus.

### BACKGROUND ART

[0002] In a microwave oven, which is a typical example of a microwave treatment apparatus, microwaves radiated from a magnetron is supplied to a treatment chamber surrounded by metal walls so that a heating target, such as food, placed in the treatment chamber is dielectrically heated.

[0003] Microwaves are repeatedly reflected on the walls of the treatment chamber. The phase of a reflected wave reflected on a metal wall shifts by 180 degrees with respect to an incident wave on the metal wall. Assuming that the line perpendicular to the metal wall is a reference line, the incident angle, which is an angle between the reference line and the incident wave, is equal to a reflection angle, which is an angle between the reflected wave and the reference line.

[0004] The size of the treatment chamber is sufficiently larger than the wavelength (about 120 mm) of microwaves in general. For this reason, a standing wave occurs in the treatment chamber due to the behaviors of the incident wave and the reflected wave at the metal wall. The standing wave has anti-nodes that constantly appear at locations with an intense electric field and nodes that constantly appear at locations with a weak electric field.

[0005] The heating target is heated intensively when placed at a location where an anti-node of the standing wave appears, whereas the heating target is not so much heated when placed at a location where a node of the standing wave appears. This is a primary cause of uneven heating in the microwave oven.

[0006] Possible methods for reducing such uneven heating caused by a standing wave and promoting even heating include a turn-table system of rotating a table to turn a heating target and a rotary antenna system of rotating an antenna for radiating microwaves.

[0007] There is also proposed a technique that actively uses localized heating opposite to the even heating (see, for example, Non-Patent Literature 1). In the device described in Non-Patent Literature 1 includes a plurality of microwave generators each constituted by a GaN semiconductor element, and supplies outputs of the microwave generators to a treatment chamber from various locations. Two supplied microwaves are provided with a phase difference so that microwaves are thereby concentrated on a heating target, thereby achieving localized heating.

## Citation List

### Non-Patent Literature

- 5 [0008] Non-Patent Literature 1: National Research and Development Agency, New Energy and Industrial Technology Development Organization et. al, "Development of industrial microwave heating system that uses GaN amplifier modules as heat sources," January 25, 2016

### SUMMARY

10 [0009] The above-described conventional in microwave treatment apparatus, however, since microwaves need to be supplied from a plurality of locations to the treatment chamber, which leads to the problem of complication and size increase in the apparatus.

15 [0010] For example, in cases where a plurality of heating targets are heated at the same time, one of the heating targets does not absorb all the microwaves even if the microwaves are intended to be focused on this heating target. Microwaves that have not been absorbed in that heating target enter the other heating target. Thus, it is difficult to perform localized heating on a plurality of heating targets as intended.

20 [0011] It is therefore an object of the present disclosure to provide a microwave treatment apparatus capable of heating each of a plurality of heating targets as intended by controlling a standing wave distribution in a treatment chamber.

25 [0012] A microwave treatment apparatus according to an aspect of the present disclosure includes: a treatment chamber configured to accommodate a heating target; a microwave supply configured to supply microwaves to the treatment chamber; and a resonator unit having a resonance frequency in a frequency band of the microwaves. The resonator unit includes a plurality of patch resonator disposed such that at least three patch resonators are arranged along an orientation of a polarization plane generated on a metal wall constituting the treatment chamber.

30 [0013] The microwave treatment apparatus of this aspect is capable of controlling a standing wave distribution in the treatment chamber, that is, a microwave energy distribution. As a result, in the case of heating a plurality of heating targets at simultaneously, the microwave treatment apparatus of this aspect is capable of adjusting microwave energy absorbed in each of the heating targets.

### BRIEF DESCRIPTION OF DRAWINGS

#### [0014]

35 [FIG. 1] FIG. 1 is a perspective view illustrating a configuration of a microwave treatment apparatus according to a first exemplary embodiment of the present disclosure.

[FIG. 2] FIG. 2 is a plan view illustrating a configuration of a microwave treatment apparatus according to a first exemplary embodiment of the present disclosure.

ration of a resonator unit in the first exemplary embodiment.

[FIG. 3A] FIG. 3A is a graph showing a frequency characteristic of a reflection phase generated by the resonator unit.

[FIG. 3B] FIG. 3B is a graph showing a frequency characteristic of the reflection phase generated by the resonator unit.

[FIG. 4A] FIG. 4A is a perspective view of a waveguide for describing an electric field generated in the waveguide.

[FIG. 4B] FIG. 4B is a cross-sectional view of the waveguide for describing an electric field generated in the waveguide.

[FIG. 4C] FIG. 4C is a perspective view of the waveguide for describing an electric field radiated from a waveguide opening.

[FIG. 5] FIG. 5 is a view showing characteristics of an electric field in a treatment chamber and a current vector on a patch surface.

[FIG. 6A] FIG. 6A is a view for describing a reason for disposing three square patch resonators.

[FIG. 6B] FIG. 6B is a view for describing a reason for disposing three square patch resonators.

[FIG. 6C] FIG. 6C is a view for describing a reason for disposing three square patch resonators.

[FIG. 7] FIG. 7 is a cross-sectional view of the microwave treatment apparatus of the first exemplary embodiment in a state where two heating targets are accommodated.

[FIG. 8A] FIG. 8A is a view illustrating an electric field distribution in a treatment chamber in a case where no resonator unit is provided.

[FIG. 8B] FIG. 8B is a view illustrating an electric field distribution in the treatment chamber in a case where a resonator unit is provided.

[FIG. 9] FIG. 9 is a plan view illustrating a configuration of a resonator unit according to a second exemplary embodiment.

[FIG. 10A] FIG. 10A is a view illustrating an example of arrangement of a resonator unit and a power feeder on a metal wall of a treatment chamber.

[FIG. 10B] FIG. 10B is a view illustrating another example of arrangement of the resonator unit and the power feeder on the metal wall of the treatment chamber.

[FIG. 11] FIG. 11 is a plan view illustrating a configuration of a resonator unit according to a third exemplary embodiment.

[FIG. 12A] FIG. 12A is a cross-sectional view illustrating a configuration of a microwave treatment apparatus according to the third exemplary embodiment.

[FIG. 12B] FIG. 12B is a transverse cross-sectional view taken along line 12B-12B in FIG. 12A.

[FIG. 13A] FIG. 13A is a longitudinal cross-sectional view illustrating another configuration of the microwave treatment apparatus of the third exemplary em-

bodiment.

[FIG. 13B] FIG. 13B is a transverse cross-sectional view taken along line 13B-13B in FIG. 13A.

[FIG. 14] FIG. 14 is a perspective view illustrating a configuration of a microwave treatment apparatus according to a fourth exemplary embodiment of the present disclosure.

[FIG. 15] FIG. 15 is a view showing a characteristic of a resonator unit illustrated in FIG. 14.

[FIG. 16] FIG. 16 is a cross-sectional view illustrating a configuration of a microwave treatment apparatus according to a fifth exemplary embodiment of the present disclosure.

## DESCRIPTION OF EMBODIMENTS

**[0015]** A microwave treatment apparatus of a first aspect of the present disclosure includes: a treatment chamber configured to accommodate a heating target; a microwave supply configured to supply microwaves to the treatment chamber; and a resonator unit having a resonance frequency in a frequency band of the microwaves. The resonator unit includes a plurality of patch resonator disposed such that at least three patch resonators are arranged along an orientation of a polarization plane generated on a metal wall constituting the treatment chamber.

**[0016]** In a microwave treatment apparatus of a second aspect of the present disclosure, the plurality of patch resonators are disposed such that the at least three patch resonators are arranged along each of a longitudinal axis and a lateral axis.

**[0017]** In a microwave treatment apparatus of a third aspect of the present disclosure, in addition to the second aspect, the plurality of patch resonators include at least five square patch resonators arranged in a cross pattern.

**[0018]** In a microwave treatment apparatus of a fourth aspect of the present disclosure, in addition to the first aspect, the plurality of patch resonators are disposed such that the at least three patch resonators are radially arranged along each of a longitudinal axis, a lateral axis, and an oblique axis.

**[0019]** In a microwave treatment apparatus of a fifth aspect of the present disclosure, in addition to the fourth aspect, the patch resonator is a circular patch resonator.

**[0020]** In a microwave treatment apparatus of a sixth aspect of the present disclosure, the microwave supply includes a microwave generator and a controller configured to control an oscillation frequency of the microwave generator. The resonator unit includes a plurality of resonator units having different resonance frequencies. The controller switches the resonator unit that oscillates among the plurality of resonator units by controlling the oscillation frequency.

**[0021]** In a microwave treatment apparatus of a seventh aspect of the present disclosure, in addition to the sixth aspect, the resonator unit includes a plurality of resonator units. Each of the plurality of resonator units is

disposed in a corresponding one of a plurality of divided regions on the metal wall constituting the treatment chamber. The plurality of resonator units have different resonance frequencies.

**[0022]** In a microwave treatment apparatus of an eighth aspect of the present disclosure, in addition to the sixth aspect, each of the plurality of resonator units has a resonance frequency in accordance with an order in arrangement of the plurality of resonator units.

**[0023]** In a microwave treatment apparatus of a ninth aspect of the present disclosure, in addition to the eighth aspect, each of the plurality of resonator units includes a conductor having a length in accordance with an order in arrangement of the plurality of resonator units.

**[0024]** Hereafter, exemplary embodiments of the microwave treatment apparatus according to the present disclosure will be described with reference to the drawings. The microwave treatment apparatus according to one exemplary embodiment is a microwave oven. The microwave treatment apparatus of the present disclosure is not limited to the microwave oven, and include, for example, a heat treatment apparatus, a chemical reaction treatment apparatus, and a semiconductor manufacturing apparatus, which utilize a dielectric heating process.

#### First Exemplary Embodiment

**[0025]** With reference to FIGS. 1 through 8B, a first exemplary embodiment of the present disclosure will be described. FIG. 1 is a perspective view of microwave treatment apparatus 100 according to this exemplary embodiment.

**[0026]** As illustrated in FIG. 1, microwave treatment apparatus 100 includes treatment chamber 101 surrounded by metal walls, and microwave supply 160 configured to supply microwaves to treatment chamber 101. Microwave supply 160 includes waveguide 102, power feeder 103, microwave generator 104, and controller 105.

**[0027]** Waveguide 102 has a rectangular-shaped cross section and transmits microwaves in a TE<sub>10</sub> mode. Power feeder 103 is a waveguide opening formed in a connection portion between waveguide 102 and treatment chamber 101. The center of the waveguide opening is positioned at an intersection point of has center line L1 along the side-to-side axis and center line L2 along the forward and backward axis of treatment chamber 101 in FIG. 1. The waveguide opening has a rectangular shape whose two sides are parallel to center lines L1 and L2.

**[0028]** Controller 105 receives information on heating treatment, and causes microwave generator 104 to generate electric power having an output and a frequency based on the information.

**[0029]** In treatment chamber 101, resonator unit 106 is disposed on the ceiling facing power feeder 103. FIG. 2 is a plan view illustrating a configuration of resonator

unit 106. As illustrated in FIG. 2, resonator unit 106 includes three square patch resonators 106a arranged in a 3×1 matrix pattern.

**[0030]** Each square patch resonator 106a includes dielectric 106b and square conductor 106c. Square patch resonators 106a has a resonance frequency between 2.4 GHz to 2.5 GHz, which range is a frequency band of microwaves generated by microwave generator 104.

**[0031]** FIGS. 3A and 3B are graphs showing frequency characteristics of a reflection phase generated by square patch resonators. The ordinate in FIG. 3A represents the reflection phase, and the ordinate in FIG. 3B represents an absolute value of the reflection phase.

**[0032]** As shown in FIG. 3A, the phase of a reflection coefficient (hereinafter referred to as a reflection phase) of square patch resonator 106a seen from square conductor 106c varies from approximately +180 degrees to approximately -180 degrees in a frequency band of 2.4 GHz to 2.5 GHz. In the characteristic shown in FIG. 3A, the resonance frequency of square patch resonator 106a is set at 2.45 GHz.

**[0033]** FIG. 3B shows an absolute value of the ordinate of FIG. 3A. As shown in FIG. 3B, the reflection phase is 180 degrees at almost all the frequencies, but decreases to zero degrees near 2.45 GHz. When the length of square conductor 106c is set at about a half of the wavelength of a current flowing in square conductor 106c, resonance occurs.

**[0034]** For example, the wavelength of microwaves at 2.45 GHz, which is used in a typical microwave oven, is about 120 mm in the air having a dielectric constant of one. Thus, in a case where dielectric 106b has a dielectric constant close to 1 (one), for example, is foam polystyrene, it is sufficient to set the length of square conductor 106c at about 60 mm. Even in a case where the length of square conductor 106c is 53 mm, for example, resonance occurs.

**[0035]** If a general-purpose substrate material or resin material is selected for dielectric 106b, the dielectric constant is larger than one (about 2 to 5). With a large dielectric constant, the wavelength of microwaves tends to be short. Thus, square conductor 106c can be made short.

**[0036]** The surface opposite to the patch surface, on which square conductor 106c of resonator unit 106 is disposed, has the same potential as the metal wall of treatment chamber 101.

**[0037]** Here, an orientation of an electric field of microwaves radiated from power feeder 103 will be described with reference to FIGS. 4A through 4C.

**[0038]** FIGS. 4A through 4C are views for describing an electric field generated in a waveguide. FIG. 4A is a perspective view of the waveguide. FIG. 4B is a cross-sectional view of the waveguide when seen from the front of an opening. FIG. 4C is a view for describing an electric field radiated from the waveguide opening.

**[0039]** Microwaves are transmitted by waveguide 102 in a positive direction of an Z axis shown in FIG. 4A, and

are radiated from power feeder 103. When width  $a$  of waveguide 102 is set at a value between  $1/2$  of wavelength  $\lambda$  of microwaves to wavelength  $\lambda$  of microwaves and height  $b$  of waveguide 102 is set at  $1/2$  of wavelength  $\lambda$  of microwaves, waveguide 102 transmits microwaves in the TE<sub>10</sub> mode.

**[0040]** As illustrated in FIG. 4B, in the TE<sub>10</sub> mode, an electric field represented by arrow E1 along the height axis occurs, and a magnetic field represented by arrow H1 along the width axis occurs. The electric field is at maximum at the center along the width axis in the waveguide 102, and is at zero at both ends in the waveguide 102. Accordingly, an electric field intensity distribution is represented as broken line E2.

**[0041]** As illustrated in FIG. 4C, in the TE<sub>10</sub> mode, an electric field is radiated from power feeder 103 in a positive direction along the Z axis. A vector component of this electric field vibrates only along the Y axis (i.e., along the height axis of the waveguide) in a manner similar to that in arrow E1, and is transmitted along the Z axis with time. Accordingly, the electric field is transmitted as indicated by broken line E3.

**[0042]** After having been radiated from waveguide 102, the electric field vector mainly vibrates only along the Y axis. This vibration direction of the electric field vector is called a polarized electromagnetic radiation, and a plane formed by the vibration direction and the transmission direction (i.e., YZ plane in this case) is called a polarization plane.

**[0043]** In general, in the waveguide for transmitting microwaves in the TE<sub>10</sub> mode, the polarization plane is a plane (YZ plane) formed by the height axis (Y axis) and the transmission direction (Z axis) of the waveguide. Similarly, in FIG. 1, microwaves radiated from waveguide 102 to treatment chamber 101 through power feeder 103 have a polarization plane represented by broken line E4 and formed by the vibration direction (direction of dot-dash line L1 in FIG. 1) and the transmission direction (upward direction in FIG. 1).

**[0044]** In treatment chamber 101, microwaves are absorbed in the heating target in treatment chamber 101 while being repeatedly reflected on the metal walls. An electric field component in treatment chamber 101 is mainly generated only in a direction parallel to the polarization plane, and is hardly generated in other directions (e.g., direction L2 component in FIG. 1).

**[0045]** In this exemplary embodiment, as illustrated in FIG. 1, resonator unit 106 is disposed including three square patch resonators 106a arranged along the polarization plane represented by broken line E4.

**[0046]** FIG. 5 is a view showing characteristics of an electric field in treatment chamber 101 and a current vector on the patch surfaces of square patch resonators 106a in a case where the number and positions of square patch resonators 106a are changed. FIG. 5 shows, in the order from the top, an analytic model, an electric field on observation plane O1, an electric field on observation plane O2, and a current vector on the patch surfaces of square

patch resonators 106a.

**[0047]** The analytic models shown at the top row in FIG. 5 have configurations in each of which waveguide 102 is connected to treatment chamber 101, as in FIG. 1. It should be noted that these analytic models are vertically inverted, as compared to the case of FIG. 1.

**[0048]** Observation plane O1 is a cross section at the center of treatment chamber 101 along the forward and backward axis, that is, a cross section along dot-dash line L2 in FIG. 1, and is orthogonal to the polarization plane represented by broken line E4 in FIG. 1. Observation plane O2 is located close to the left in treatment chamber 101, orthogonal to observation plane O1, and parallel to the polarization plane represented by dot-dash line L1 and broken line E4 in FIG. 1.

**[0049]** In the second row near the middle in FIG. 5, an electric field on observation plane O1 and an electric field on observation plane O2, for example, are shown in electric field intensity diagrams. In the bottom row in FIG. 5, current vectors on the patch surfaces of square patch resonators 106a are shown. The positions of square patch resonators 106a vary among the analytic models, and thus, current vectors on the patch surfaces are shown at positions (back, center, and front) corresponding to the positions of square patch resonators 106a. Isosceles triangles in the drawing represent orientations of the current vectors.

**[0050]** As illustrated in FIG. 5, four types of analyses were conducted. In analysis A, square patch resonators 106a are not used. In analysis B, one square patch resonator 106a is disposed at the center along the forward and backward axis. In analysis C, one of two square patch resonators 106a is disposed at the back and the other at the front. In analysis D, one of three square patch resonators 106a is disposed at the back, another one at the center, and the last one at the front.

**[0051]** Here, the degree to which observation plane O2 is disposed close to the left will be described. First, with reference to an electric field distribution on observation plane O1 in analysis A, a location where an anti-node of a standing wave occurs is selected on the bottom surface of treatment chamber 101 of the analytic model. In FIG. 5, location 111 is selected.

**[0052]** A plane passing through location 111 on observation plane O1 and orthogonal to observation plane O1 is set as observation plane O2. With reference to an electric field distribution on observation plane O2 at this time, an anti-node of the standing wave occurs at location 112 as an intersection point of observation plane O1 and observation plane O2.

**[0053]** Next, focusing on an electric field on observation plane O1 and an electric field on observation plane O2, advantages of square patch resonators 106a are studied by examining changes of analyses B, C, and D from analysis A.

**[0054]** In analysis A, the electric field distribution on each of observation plane O1 and observation plane O2 are bilaterally symmetric. An electric field at location 111

is intense, electric fields at location 113 and location 114 are weak, and an electric field at location 112 is about a middle between the electric fields at location 111 and location 113.

**[0055]** In analysis B, the electric fields at location 111 and location 112 are weak. In particular, a node of the standing wave occurs at location 112 on observation plane O2. The electric field on observation plane O1 is not bilaterally symmetric any more.

**[0056]** In analysis B, one square patch resonator 106a is disposed at the center in the forward and backward axis on observation plane O2. That is, in analysis B, one square patch resonator 106a is disposed at a location corresponding to an anti-node of the standing wave in analysis A. A result of analysis B shows that square patch resonator 106a disposed at the location corresponding to the anti-node of the standing wave changes the anti-node of the standing wave to the node.

**[0057]** In characteristics shown in FIGS. 3A and 3B, the reflection phases of square patch resonators 106a with respect to a frequency of 2.45 GHz is approximately zero degrees. This means that the phase difference between an incident wave on the patch surface and a reflected wave from the patch surface is approximately zero degrees. Considering the fact that the phase difference between an incident wave and a reflected wave on a typical metal wall is 180 degrees, it is shown that a standing wave distribution different from a normal distribution is formed near resonator unit 106.

**[0058]** If the reflection phase is approximately zero degrees, an impedance becomes infinite. Accordingly, a high frequency current flowing in the patch surfaces is reduced, and microwaves move away from resonator unit 106. This is a cause of weakening of an electric field near resonator unit 106. It is assumed that this influence disturbs bilateral symmetry of observation plane O1. This effect will be referred to as a first effect.

**[0059]** In analysis C, as in the case of analysis A, the electric fields at location 111 and location 112 are intense. The electric fields are weak at location 113 and location 114 where square patch resonators 106a are disposed. In analysis A, nodes of the standing wave occur at location 113 and location 114. Specifically, a result of analysis C shows that square patch resonators 106a disposed at nodes of the standing wave where electric fields are weak do not significantly affect standing wave distributions.

**[0060]** In analysis D, the electric fields are weak at location 111 and location 112 and an intense electric field is generated in region 115. The bilateral symmetry on observation plane O1 is disturbed. A result of analysis D seems to show that the effect of analysis B and the effect of analysis C are combined. In addition to this, however, an intense electric field is generated in region 115. This is an effect unique to the case where three square patch resonators 106a are disposed.

**[0061]** As a hint for study, a current vector on the patch surface shown at the bottom row in FIG. 5 in analysis D will be considered. Comparing to three current vectors,

a large number of downward vectors are observed in current vector 116 and current vector 117 in FIG. 5, whereas a large number of upward vectors are observed in current vector 118 in FIG. 5. With reference to this, a hypothesis on an effect of arrangement of three square patch resonators 106a will be described with reference to FIGS. 6A through 6C.

**[0062]** FIGS. 6A through 6C are views for describing a reason for arranging three square patch resonators 106a. FIG. 6A is a view for describing an electric field in a case where two separate square patch resonators are disposed in an intense electric field. FIG. 6B is a view for describing an electric field in an opposite direction generated when three square patch resonators are disposed. FIG. 6C is a view for describing that the intense electric field in FIG. 6B becomes a weak electric field.

**[0063]** Two square patch resonators 106a in FIG. 6A correspond to two square patch resonators 106a shown in analysis B in FIG. 5. As illustrated in FIG. 6A, current vectors 116 and 117 in the same direction are generated by intense electric field 119, and electric fields 120 and 121 in opposite directions are generated between two square patch resonators 106a.

**[0064]** As illustrated in FIG. 6B, when another square patch resonator 106a is additionally disposed between two square patch resonators 106a in FIG. 6A, induction field 122 in the same direction as electric field 120, and induction field 123 in the same direction as electric field 121 are excited.

**[0065]** As illustrated in FIG. 6C, current vector 118 in the opposite direction is generated by induction fields 122 and 123 in square patch resonator 106a at the middle. Accordingly, electric field 124 in the opposite direction that cancels intense electric field 119 occurs. Consequently, the intense electric field can be weakened by the electric fields in the opposite direction generated by three square patch resonators 106a.

**[0066]** As described above, in the hypothesis, current vector 118 generated in middle square patch resonator 106a is in the direction opposite to current vectors 116 and 117 generated in square patch resonators 106a at the back and the front, respectively. This result coincides with that in analysis D in FIG. 5. This effect will be referred to as a second effect. The second effect is supposed to be different from the first effect obtained by disposing three square patch resonators 106a.

**[0067]** Thus, analysis B in FIG. 5 shows only the first effect that one square patch resonator 106a disposed at a position corresponding to the anti-node of the standing wave weaken the electric field. Analysis D in FIG. 5 shows that the second effect that three square patch resonators 106a weaken the electric field is combined with the first effect.

**[0068]** Thus, analysis D shows the effect that electric fields near square patch resonators 106a are further weakened as compared to analysis B. It is conceivable that an electric field at a location away from square patch resonator 106a is relatively intensified as a result so that

an intense electric field is generated in region 115.

**[0069]** The second effect is that the electric field is weakened when square patch resonator 106a is disposed at a location corresponding to an anti-node of the standing wave, whereas the standing wave does not change even when square patch resonator 106a is disposed at a location corresponding to a node of the standing wave.

**[0070]** This is because when square patch resonator 106a is disposed at the location corresponding the node of the standing wave, currents in opposite directions flow in square patch resonators 106a at the back and the front, and electric fields in the same direction are generated between two square patch resonators 106a, and even when the middle resonator unit is disposed, neither induction fields nor currents in opposite directions described above are generated.

**[0071]** A case where treatment chamber 101 accommodates two heating targets will now be described. FIG. 7 is a cross-sectional view of microwave treatment apparatus 100 in a state where two heating targets are accommodated.

**[0072]** As illustrated in FIG. 7, treatment chamber 101 includes mounting plate 107 disposed above power feeder 103. Mounting plate 107 is made of a material having a low dielectric loss. Heating targets 108 and 109 are mounted on mounting plate 107. In this state, microwave generator 104 supplies microwaves 110.

**[0073]** FIGS. 8A and 8B are views showing electric field distributions in treatment chamber 101 illustrated in FIG. 7. FIG. 8A shows an electric field distribution in a case where resonator unit 106 is not provided. FIG. 8B shows an electric field distribution in a case where resonator unit 106 is disposed on a right portion of the ceiling of treatment chamber 101.

**[0074]** As shown in FIG. 8A, in the case where resonator unit 106 is not provided, an electric field distribution having substantially bilateral symmetry occurs in treatment chamber 101, and a more uniform standing wave distribution appears.

**[0075]** On the other hand, as shown in FIG. 8B, when resonator unit 106 is disposed on the right portion of the ceiling of treatment chamber 101, there appears a standing wave distribution in which a weak electric field occurs in a right portion of treatment chamber 101 and an intense electric field occurs in a left portion of treatment chamber 101. In this case, electric power absorbed in heating target 108 was increased to be about 2.7 times as large as that of heating target 109.

**[0076]** As described above, microwave treatment apparatus 100 of this exemplary embodiment includes treatment chamber 101 surrounded by the metal walls, microwave supply 160 configured to supply microwaves to treatment chamber 101, and resonator unit 106 having a resonance frequency in a frequency band of microwaves. Resonator unit 106 includes three patch resonators (square patch resonators 106a) arranged along the orientation of the polarization plane generated on the

metal walls constituting treatment chamber 101.

**[0077]** In this configuration, when microwaves having a frequency near a resonance frequency are supplied to treatment chamber 101, microwaves are reflected on a surface of resonator unit 106 with a phase difference of approximately zero degrees. On the other hand, microwaves are reflected on the metal walls of treatment chamber 101 with a phase difference of 180 degrees. Accordingly, the direction of an electric field is reversed. As a result, a certain change occurs in a standing wave distribution appearing in treatment chamber 101.

**[0078]** In particular, when three square patch resonators 106a are disposed along the orientation of the polarization plane, a change of a standing wave distribution appearing in treatment chamber 101 can be more distinct.

**[0079]** First, when three square patch resonators 106a are disposed at anti-nodes of the standing wave, electric fields and currents in the same direction are generated at square patch resonators 106a at both ends. An electric field and a current in the direction opposite to those in square patch resonators 106a at both ends occur at middle square patch resonator 106a. This electric field in the opposite direction acts so as to cancel the intense electric field so that an anti-node of the standing wave changes to a node.

**[0080]** Second, when three square patch resonators 106a are disposed at nodes of the standing wave, the standing wave does not change. Specifically, when three square patch resonators 106a are disposed along the orientation of the polarization plane, nodes of the standing wave constantly occur at the locations corresponding to three square patch resonators 106a, irrespective of whether the locations of square patch resonators 106a are locations corresponding to anti-nodes or locations corresponding to nodes of the standing wave.

**[0081]** With this effect, a standing wave distribution in treatment chamber 101, that is, microwave energy distribution, can be controlled. Thus, in the case of heating a plurality of heating targets at the same time, desired microwave energy can be absorbed in each of the heating targets.

**[0082]** For example, it is possible to perform such control that causes a first heating target to absorb microwave energy less than a second heating target by controlling such that a node of the standing wave occurs at a location at which the first heating target is placed.

**[0083]** In this exemplary embodiment, resonator unit 106 includes flat square patch resonators 106a. Accordingly, resonator unit 106 can be disposed with substantially no loss of an effective inner volume of treatment chamber 101.

**[0084]** Square patch resonators 106a are disposed such that the patch surface faces the inside of treatment chamber 101 and the surface opposite to the patch surface has the same potential as the metal walls of treatment chamber 101. With this configuration, an effective inner volume of treatment chamber 101 can be sufficient-

ly obtained.

**[0085]** Three square patch resonators 106a are disposed on one of the metal walls constituting treatment chamber 101. Accordingly, a change of a standing wave distribution caused by resonator unit 106 can be easily predicted. As a result, the heating targets can be heated as intended.

**[0086]** In this exemplary embodiment, resonator unit 106 is disposed on a metal wall of treatment chamber 101 opposite to a metal wall of treatment chamber 101 on which power feeder 103 is disposed. Accordingly, a microwave energy distribution can be concentrated near power feeder 103. As a result, heating targets can be efficiently heated together with microwave energy from power feeder 103.

**[0087]** Microwave supply 160 includes microwave generator 104, and controller 105 configured to control an oscillation frequency and an output of microwave generator 104. In this manner, a plurality of heating targets can be heated at the same time.

**[0088]** Resonator unit 106 may include four or more square patch resonators 106a. In this case, the center position of the four or more patch resonators varies depending on a combination of three adjacent patch resonators out of the four or more patch resonators. This corresponds to the fact that a plurality of combinations substantially exists for the combination of three patch resonators.

**[0089]** Thus, even if the location of an anti-node of the standing wave is shifted from an expected location, for example, a combination of other three patch resonators different from an expected combination of three patch resonators might function similarly to resonator unit 106 described above.

#### Second Exemplary Embodiment

**[0090]** With reference to FIGS. 9 through 10B, a second exemplary embodiment of the present disclosure will be described. Microwave treatment apparatus 100 according to this exemplary embodiment has basically the same configuration as that of the first exemplary embodiment except for resonator unit 106.

**[0091]** FIG. 9 is a view illustrating a configuration of resonator unit 106 in this exemplary embodiment. As illustrated in FIG. 9, resonator unit 106 includes square conductor 106c having a square shape. Supposing square conductor 106c includes nine regions divided into a 3×3 matrix pattern, dielectric 106b is provided in each of five regions included in the middle row and the middle column.

**[0092]** That is, three square patch resonators 106a are arranged along the lateral axis in the middle row, whereas three square patch resonators 106a are arranged along the longitudinal axis in the middle column. Resonator unit 106 of this exemplary embodiment includes five square patch resonators 106a arranged in a cross pattern.

**[0093]** FIGS. 10A and 10B are views illustrating exam-

ples of arrangement of resonator unit 106 and power feeder 103 on one metal wall (e.g., ceiling) of treatment chamber 101.

**[0094]** In the configuration illustrated in FIG. 10A, power feeder 103 includes a laterally elongated waveguide opening. Thus, the vibration direction of electric field E1 is oriented along the longitudinal axis (upward and downward axis in FIG. 10A), and the polarization plane is oriented along the longitudinal axis.

**[0095]** Thus, in this configuration, three square patch resonators 106a arranged along the longitudinal axis out of five square patch resonators 106a arranged in a cross pattern function in a manner similar to resonator unit 106 of the first exemplary embodiment.

**[0096]** In the configuration illustrated in FIG. 10B, power feeder 103 has a longitudinally elongated waveguide opening. Thus, the vibration direction of electric field E1 is oriented along the lateral axis (side-to-side axis in FIG. 10A), and the polarization plane is oriented along the lateral axis.

**[0097]** Thus, in this configuration, three square patch resonators 106a arranged along the lateral axis out of five square patch resonators 106a arranged in a cross pattern function in a manner similar to resonator unit 106 of the first exemplary embodiment. In this exemplary embodiment, the longitudinal axis and the lateral axis correspond to the forward and backward axis and the side-to-side axis, respectively, of treatment chamber 101 in FIG. 1.

**[0098]** In the case of a microwave oven, in general, treatment chamber 101 has a laterally elongated rectangular solid shape and power feeder 103 is disposed in parallel with the outer shape of treatment chamber 101, as illustrated in FIGS. 10A and 10B. However, selection of the configuration illustrated in FIG. 10A or the configuration illustrated in FIG. 10B depends on design. Thus, if resonator unit 106 has the configuration illustrated in FIG. 9, resonator unit 106 functions in a manner similar to resonator unit 106 of the first exemplary embodiment in any of the configuration illustrated in FIG. 10A and the configuration illustrated in FIG. 10B.

**[0099]** As described above, in this exemplary embodiment, resonator unit 106 has five patch resonators (square patch resonators 106a) arranged in a cross pattern. With this configuration, anti-nodes of the standing wave can be changed to nodes for any of the polarization plane along the longitudinal axis and the polarization plane along the lateral axis. In this exemplary embodiment, a standing wave distribution in treatment chamber 101, that is, a microwave energy distribution, can be controlled.

**[0100]** In this exemplary embodiment, resonator unit 106 includes five square patch resonators 106a arranged in a cross pattern. That is, resonator unit 106 includes the five patch resonators in total arranged such that three patch resonators are arranged along each of the longitudinal axis and the lateral axis. With this configuration, the number of necessary square patch resonators 106a

can be reduced, as compared to a case where on resonator unit 106 of the first exemplary embodiment is provided along each of the longitudinal axis and the lateral axis.

**[0101]** In resonator unit 106, four or more square patch resonators 106a may be disposed along each of the longitudinal axis and the lateral axis. In this case, the center position of the four or more patch resonators varies depending on a combination of three adjacent patch resonators out of the four or more patch resonators. This corresponds to the fact that a plurality of combinations substantially exist for the combination of three patch resonators.

**[0102]** Thus, even if the location of an anti-node of the standing wave is shifted from an expected location, for example, a combination of other three patch resonators different from an expected combination of three patch resonators might function similarly to resonator unit 106 in the first exemplary embodiment.

### Third Exemplary Embodiment

**[0103]** With reference to FIGS. 11 through 13B, a third exemplary embodiment of the present disclosure will be described. FIG. 11 is a plan view illustrating a configuration of resonator unit 130 according to this exemplary embodiment.

**[0104]** As illustrated in FIG. 11, resonator unit 130 includes nine circular conductors 130c arranged on a circular dielectric 130b. Out of nine circular conductors 130c, one circular conductor 130c is disposed at the center, eight circular conductors 130c are arranged at regular intervals on a circumference about center circular conductor 130c. That is, in this configuration, three circular patch resonators 130a are arranged along each of the longitudinal axis, the lateral axis, and an oblique axis.

**[0105]** In this exemplary embodiment, the longitudinal axis and the lateral axis correspond to the forward and backward axis and the side-to-side axis, respectively, of treatment chamber 101 in FIG. 1. The oblique axis is an axis forming 45 degrees with respect to each of the longitudinal axis and the lateral axis.

**[0106]** When the diameter of circular conductor 130c is set at a length of about a half of the wavelength of a current flowing on circular conductor 130c, resonance can be generated. The wavelength of microwaves at 2.45 GHz is about 120 mm in the air having a dielectric constant of one. Thus, in a case where dielectric 130b has a dielectric constant close to one, for example, is foam polystyrene, the diameter of circular conductor 130c is set at about 60 mm.

**[0107]** In this exemplary embodiment, a substrate having a dielectric constant of about 3.5,  $\tan \delta$  of about 0.004, and a thickness of about 0.6 mm is used as dielectric 130b, and circular conductor 130c is formed in a copper foil pattern on the substrate. With this configuration, the diameter of resonator unit 130 can be reduced to 38 mm.

**[0108]** FIG. 12A is a longitudinal cross-sectional view

illustrating a configuration of microwave treatment apparatus 100 according to this exemplary embodiment. FIG. 12B is a transverse cross-sectional view taken along line 12B-12B in FIG. 12A.

**[0109]** In this exemplary embodiment, microwaves are not directly radiated from waveguide 102 to treatment chamber 101, but are radiated through radiation antenna 131 to treatment chamber 101.

**[0110]** As illustrated in FIGS. 12A and 12B, radiation antenna 131 includes coupling shaft 132 coupled to waveguide 102, and radiating unit 133. Radiating unit 133 has three walls (walls 134a, 134b, and 134c), flange 135 disposed around the walls, ceiling 136, and front opening 137.

**[0111]** Radiation antenna 131 has a waveguide structure formed by walls 134a, 134b, and 134c and ceiling 136, and radiates microwaves in the direction represented by arrow 138 from front opening 137. As a result, microwave treatment apparatus 100 of this exemplary embodiment has a polarization plane including arrow 138 and perpendicular to the drawing sheet of FIG. 12B.

**[0112]** Motor 139 is engaged with coupling shaft 132, and rotates coupling shaft 132 in response to an instruction from controller 105. When radiating unit 133 rotates with the rotation of coupling shaft 132, orientation of microwaves radiated from front opening 137 and the polarization plane rotate.

**[0113]** As described above, in the structure including rotating radiation antenna 131, the polarization plane has various axes as well as the longitudinal axis and the lateral axis. Thus, resonator unit 130 having the configuration illustrated in FIG. 11 shows an effect on the polarization plane generated in the configurations of FIGS. 12A and 12B.

**[0114]** FIG. 13A is a longitudinal cross-sectional view illustrating another configuration of microwave treatment apparatus 100 according to this exemplary embodiment. FIG. 13B is a transverse cross-sectional view taken along line 13B-13B in FIG. 13A.

**[0115]** As illustrated in FIG. 13B, in this configuration, radiation antenna 131 has X-shaped circular polarized electromagnetic radiation aperture 140 provided on ceiling 136, and radiates microwaves of circular polarization from circular polarization aperture 140 upward in FIG. 13A.

**[0116]** In the first and second exemplary embodiments, microwaves radiated from the waveguide opening generates an electric field having a single vibration direction. Since microwaves also has a transmission direction, a single polarization plane is generated in this case. Such microwaves are called microwaves of linear polarization.

**[0117]** On the other hand, for microwaves of circular polarization, an electric field itself rotates about the intersection point of X-shaped circular polarization aperture 140. Accordingly, the polarization plane has various axes as well as the longitudinal axis and the lateral axis. Resonator unit 130 having the configuration illustrated in FIG.

11 shows an effect on the polarization plane generated in the configurations of FIGS. 13A and 13B.

**[0118]** As described above, in this exemplary embodiment, resonator unit 130 includes one circular patch resonator 130a disposed at the center, and eight circular patch resonators 130a arranged at regular intervals on a circumference about the one circular patch resonator 130a. In this configuration, three patch resonators are arranged along each of the longitudinal axis, the lateral axis, and the oblique axis.

**[0119]** With this configuration, along each of the longitudinal axis, the lateral axis, and the oblique axis, resonator unit 130 functions in a manner similar to resonator unit 106 in the first exemplary embodiment.

**[0120]** In this exemplary embodiment, resonator unit 130 is constituted by circular patch resonators 130a including circular conductor 130c. In the patch resonators, whether resonance occurs or not depends on the length of the conductor. The circular conductor has a uniform length along all of the longitudinal, lateral, and oblique axes.

**[0121]** Thus, the use of resonator unit 130 allow resonance to occur on any of the longitudinal, lateral, and oblique polarization planes. In this exemplary embodiment, a standing wave distribution in treatment chamber 101, that is, a microwave energy distribution, can be controlled.

**[0122]** Resonator unit 130 of this exemplary embodiment is not limited to the configuration described above. For example, resonator unit 130 may nine patch resonators arranged in a 3×3 matrix pattern. That is, in this exemplary embodiment, resonator unit 130 includes nine patch resonators in total in which three patch resonators are radially arranged along each of the longitudinal axis, the lateral axis, and the oblique axes.

**[0123]** In resonator unit 130, four or more circular patch resonators 130a may be arranged along each of longitudinal axis, the lateral axis, and the oblique axis. In this case, the center position of the four or more patch resonators varies depending on a combination of three adjacent patch resonators out of the four or more patch resonators. This corresponds to the fact that a plurality of combinations substantially exist for the combination of three patch resonators.

**[0124]** Thus, even if the location of an anti-node of the standing wave is shifted from an expected location, for example, a combination of other three patch resonators different from an expected combination of three patch resonators might function similarly to resonator unit 106 in the first exemplary embodiment.

#### Fourth Exemplary Embodiment

**[0125]** With reference to FIGS. 14 and 15, a fourth exemplary embodiment of the present disclosure will be described. FIG. 14 is a perspective view illustrating a configuration of microwave treatment apparatus 100 according to this exemplary embodiment. FIG. 15 is a view

showing a characteristic of a resonator unit illustrated in FIG. 14.

**[0126]** As illustrated in FIG. 14, microwave treatment apparatus 100 of this exemplary embodiment includes nine resonator units (resonator units 141, 142, 143, 144, 145, 146, 147, 148, and 149) arranged in a 3×3 pattern, on the ceiling of treatment chamber 101.

**[0127]** Each of resonator units 141 through 149 includes nine circular conductors arranged in a 3×3 pattern on a square dielectric. With this configuration, nine patch resonators are formed in each of resonator units 141 through 149.

**[0128]** Resonator units 141 through 149 have dielectrics having the same size. However, the diameter of a circular conductor included in a circular patch resonator of each resonator unit gradually increases in the order from resonator unit 141 to resonator unit 149. With this configuration, the resonance frequency of each resonator unit decreases by 10 MHz for each resonator unit in the order from resonator unit 141 to resonator unit 149.

**[0129]** Specifically, as shown in FIG. 15, resonance frequencies of resonator units 141, 142, 143, 144, 145, 146, 147, 148 and 149 are 2.49 GHz, 2.48 GHz, 2.47 GHz, 2.46 GHz, 2.45 GHz, 2.44 GHz, 2.43 GHz, 2.42 GHz, and 2.41 GHz, respectively. The absolute value of a reflection phase is zero degrees at these resonance frequencies.

**[0130]** In this exemplary embodiment, a resonator unit in which resonance occurs is switched by controlling the frequency of microwaves to be supplied. For example, when microwaves at a frequency of 2.49 GHz are supplied, only resonator unit 141 resonates. Accordingly, an anti-node of the standing wave can be changed to a node near a left back region where resonator unit 141 is disposed. As a result, an electric field near the left back region can be weakened.

**[0131]** When microwaves of a frequency of 2.45 GHz are supplied, an anti-node of the standing wave can be changed to a node near a center region where resonator unit 145 is disposed. As a result, an electric field in the center region can be weakened.

**[0132]** When microwaves of 2.49 GHz, 2.46 GHz, and 2.43 GHz are sequentially supplied in a time division manner, an anti-node of the standing wave can be changed to a node near a left region where resonator units 141, 144, and 147 are disposed. Accordingly, an electric field in the left region can be weakened. In this case, an electric field in a right region is intensified, and as a result, heating target 109 disposed at the right can be strongly heated.

**[0133]** In this exemplary embodiment, resonator units 141 through 149 include circular patch resonators. Alternatively, resonator units 141 through 149 may include square patch resonators. Each of resonator units 141 through 149 may be resonator unit 130 in the third exemplary embodiment.

**[0134]** In this exemplary embodiment, a resonator unit in which resonance occurs is switched by controlling the

frequency of microwaves to be supplied. Accordingly, an anti-node of the standing wave can be changed to a node near a resonator unit where resonance occurs. As a result, an electric field near the resonator unit where resonance occurs can be weakened.

#### Fifth Exemplary Embodiment

**[0135]** With reference to FIG. 16, a fifth exemplary embodiment of the present disclosure will be described. FIG. 16 is a cross-sectional view illustrating a configuration of microwave treatment apparatus 100 according to this exemplary embodiment.

**[0136]** As illustrated in FIG. 16, microwave treatment apparatus 100 of this exemplary embodiment includes resonator unit 150 disposed on the ceiling of treatment chamber 101. Resonator unit 150 includes five conductors arranged at pitch P on a dielectric disposed on the ceiling of treatment chamber 101. With this configuration, in resonator unit 150, five patch resonators (patch resonators 151, 152, 153, 154, and 155) are formed.

**[0137]** Conductors of five patch resonators have different lengths. The conductor of patch resonator 151 has length  $a_1$ , the conductor of patch resonator 152 has length  $a_2$ , the conductor of patch resonator 153 has length  $a_3$ , the conductor of patch resonator 154 has length  $a_4$ , and the conductor of patch resonator 155 has length  $a_5$ . Lengths  $a_1$  through  $a_5$  have a relationship of  $a_1 > a_2 > a_3 > a_4 > a_5$ .

**[0138]** Specifically, each of patch resonators 151 through 155 includes a conductor having a length in accordance with the order in arrangement of patch resonators 151 through 155. As a result, each of patch resonators 151 through 155 has a resonance frequency in accordance with the order in arrangement of patch resonators 151 through 155.

**[0139]** Combinations of three adjacent patch resonators out of these five patch resonators include left-end combination 161, center combination 162, and right-end combination 163. Combination 161 is constituted by patch resonators 151, 152, and 153. Combination 162 is constituted by patch resonators 152, 153, and 154. Combination 163 is constituted by patch resonators 153, 154, and 155.

**[0140]** The average lengths of conductors of patch resonators included in these combinations become shorter from combination 161 to combination 163. Accordingly, in a case where three patch resonators included in combination 161 resonate at frequency  $f_1$ , three patch resonators included in combination 162 resonate at frequency  $f_2$ , and three patch resonators included in combination 163 resonate at frequency  $f_3$ , frequencies  $f_1$  through  $f_3$  increase in this order.

**[0141]** Specifically, the length of the conductor of patch resonator 153 is set at approximately  $1/2$  of wavelength (effective length) of microwaves used in a typical microwave oven. Accordingly, frequency  $f_2$  can be set at 2.45 GHz, which is a frequency of these microwaves.

**[0142]** The length of the conductor of patch resonator 152 is slightly longer than that of patch resonator 153, and the length of the conductor of patch resonator 151 is slightly longer than that of patch resonator 152. The length of the conductor of patch resonator 154 is slightly shorter than that of patch resonator 153, and the length of the conductor of patch resonator 155 is slightly shorter than that of patch resonator 154.

**[0143]** That is, in this exemplary embodiment, the conductors of all the patch resonators have a length of approximately  $1/2$  of the wavelength (effective length) of microwaves. However, depending on the location in arrangement, the length of the conductor of each patch resonator slightly varies.

**[0144]** In this exemplary embodiment, patch resonators located at ends in center combination 162 are shared by combinations 161 and 163 adjacent to combination 162. With this configuration, three combinations each constituted by three patch resonators can be formed by using five patch resonators, without using nine patch resonators.

**[0145]** In this exemplary embodiment, the combination of patch resonators where resonance occurs can be switched by setting the frequency of microwaves to be supplied at one of frequencies  $f_1$  through  $f_3$ . Accordingly, an anti-node of the standing wave can be changed to a node near the combination of patch resonators where resonance occurs. As a result, an electric field near the combination of patch resonators where resonance occurs can be weakened.

**[0146]** In this exemplary embodiment, it can be assumed that each of the three combinations each constituted by three patch resonators may correspond to one resonator unit. That is, it can be assumed that resonator unit 150 of this exemplary embodiment includes three resonator units.

**[0147]** As illustrated in FIG. 16, the patch surfaces of five patch resonators are constituted by copper foil applied onto a single surface of one substrate material. The surface of the substrate material opposite to the patch surface contacts the ceiling of treatment chamber 101. In this manner, patch resonators 151, 152, 153, 154, and 155 can be disposed on the same single-sided substrate.

**[0148]** Patch resonator units 151, 152, 153, 154, and 155 may be constituted by a double-sided substrate. When the patch surface is disposed on one surface of the double-sided substrate and the surface of the substrate material opposite to the patch surface is brought into contact with the ceiling of treatment chamber 101, the opposite surface can be made at the same potential as that of the metal surfaces of treatment chamber 101.

**[0149]** In this exemplary embodiment, a combination of patch resonators where resonance occurs can be switched by controlling the frequency of microwaves to be supplied. Accordingly, an anti-node of the standing wave can be changed to a node near the combination of patch resonators where resonance occurs. As a result, an electric field near the combination of patch resonators

where resonance occurs can be weakened.

**[0150]** In this exemplary embodiment, resonator unit 150 is disposed only on the ceiling of treatment chamber 101. Alternatively, resonator unit 150 may be disposed on a side surface of treatment chamber 101. For example, when resonator unit 150 is disposed on the right side surface of treatment chamber 101, a localized standing wave distribution where an intense electric field occurs at the left of treatment chamber 101. As a result, a heating target placed at the left of treatment chamber 101 is more intensively heated.

**[0151]** When one of two resonator units 150 is disposed on the ceiling and the other on the right side surface, synergistic effects of two resonator units 150 might obtain advantages more than those in the case of FIG. 8B.

**[0152]** The use of the substrate as the dielectric of the resonator unit enables reduction of the size of the resonator unit. However, if energy of microwaves to be output increases, a loss may occur to generate heat or spark may occur between adjacent patches. Thus, in the case of an apparatus requiring only microwaves with small energy for, for example, a chemical reaction treatment, a dielectric substrate may be used. In the case of an apparatus requiring microwaves with large energy for, for example, heating food, another method may be employed.

**[0153]** The second effect described with reference to FIGS. 6A through 6C is to weaken an intense electric potential caused by an unstable potential of the center one of the three patch resonators separated from the ground, by using an electric field in the opposite direction generated by the three patch resonators.

**[0154]** In addition to the configurations illustrated in FIGS. 6A through 6C, a configuration in which a switch is disposed between the center patch resonator and the ground surface so as to perform switching control is also conceivable. In this case, when the switch is turned off, since the patch resonators are separated from the ground, the second effect arises. On the other hand, when the switch is turned on, the center patch resonator is grounded, and the second effect does not arise.

**[0155]** In addition, in a conceivable configuration, switches are provided in all the patch resonators in order to effectively use the switches. In this case, in general, the patch resonators are grounded by turning all the switches on so as not to cause the second effect.

**[0156]** When the patch resonators are separated from the ground by turning off the switches for at least three patch resonators, the second effect arises, and an anti-node of a standing wave near this region can be changed to a node.

**[0157]** With this method, a standing wave distribution can be controlled as intended only by on/off control of the switches without controlling the frequency or by using resonator units having the same size.

## INDUSTRIAL APPLICABILITY

**[0158]** The present disclosure is applicable to a microwave treatment apparatus configured to perform heating treatment for, for example, food and/or a chemical reaction treatment, for example.

## REFERENCE MARKS IN THE DRAWINGS

10 **[0159]**

100 microwave treatment apparatus  
101 treatment chamber  
102 waveguide  
103 power feeder  
104 microwave generator  
105 controller  
106, 130, 141, 142, 143, 144, 145, 146, 147, 148, 149, 150 resonator unit  
106a square patch resonator  
106b, 130b dielectric  
106c square conductor  
107 mounting plate  
108, 109 heating target  
110 microwaves  
130a circular patch resonator  
130c circular conductor  
151, 152, 153, 154, 155 patch resonator  
160 microwave supply

## Claims

1. A microwave treatment apparatus comprising:

a treatment chamber configured to accommodate a heating target;  
a microwave supply configured to supply microwaves to the treatment chamber; and  
a resonator unit having a resonance frequency in a frequency band of the microwaves, and includes a plurality of patch resonators disposed including at least three patch resonators arranged along an orientation of a polarization plane generated on a metal wall constituting the treatment chamber.

2. The microwave treatment apparatus according to claim 1, wherein the plurality of patch resonators are disposed including the at least three patch resonators arranged along each of a longitudinal axis and a lateral axis.

3. The microwave treatment apparatus according to claim 2, wherein the plurality of patch resonators include at least five square patch resonators arranged in a cross pattern.

4. The microwave treatment apparatus according to claim 1, wherein the plurality of patch resonators are disposed including the at least three patch resonators arranged along each of a longitudinal axis, a lateral axis, and an oblique axis. 5
5. The microwave treatment apparatus according to claim 4, wherein the patch resonator is a circular patch resonator. 10
6. The microwave treatment apparatus according to claim 1, wherein the microwave supply includes a microwave generator and a controller configured to control an oscillation frequency of the microwave generator, the resonator unit includes a plurality of resonator units having different resonance frequencies, and the controller configured to switch the resonator unit that oscillates among the plurality of resonator units by controlling the oscillation frequency. 15 20
7. The microwave treatment apparatus according to claim 6, wherein the resonator unit includes a plurality of resonator units, each of the plurality of resonator units is disposed in a corresponding one of a plurality of divided regions on the metal wall constituting the treatment chamber, and the plurality of resonator units have different resonance frequencies. 25
8. The microwave treatment apparatus according to claim 6, wherein each of the plurality of resonator units has a resonance frequency in accordance with an order in arrangement of the plurality of resonator units. 30 35
9. The microwave treatment apparatus according to claim 8, wherein each of the plurality of resonator units includes a conductor having a length in accordance with an order in arrangement of the plurality of resonator units. 40

45

50

55

FIG. 1

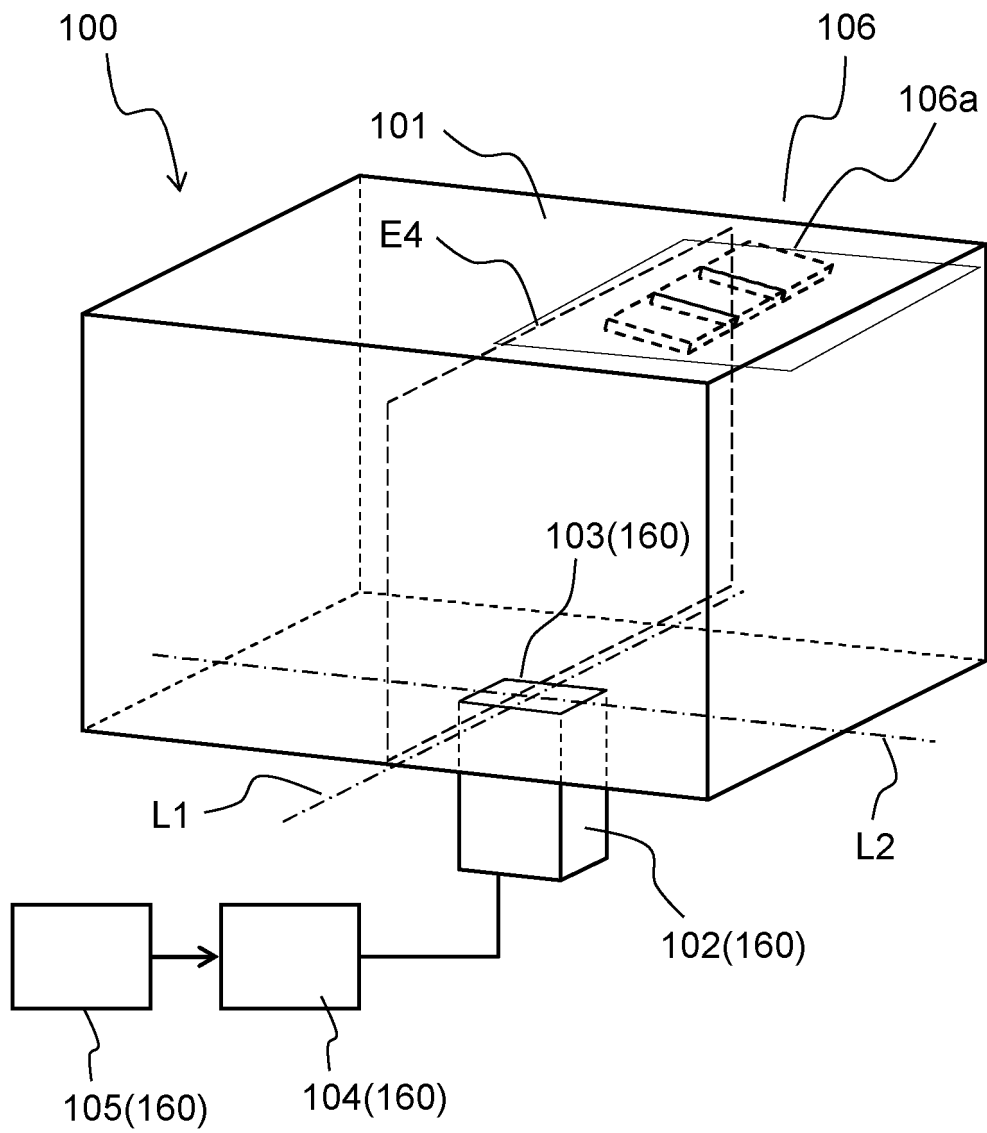


FIG. 2

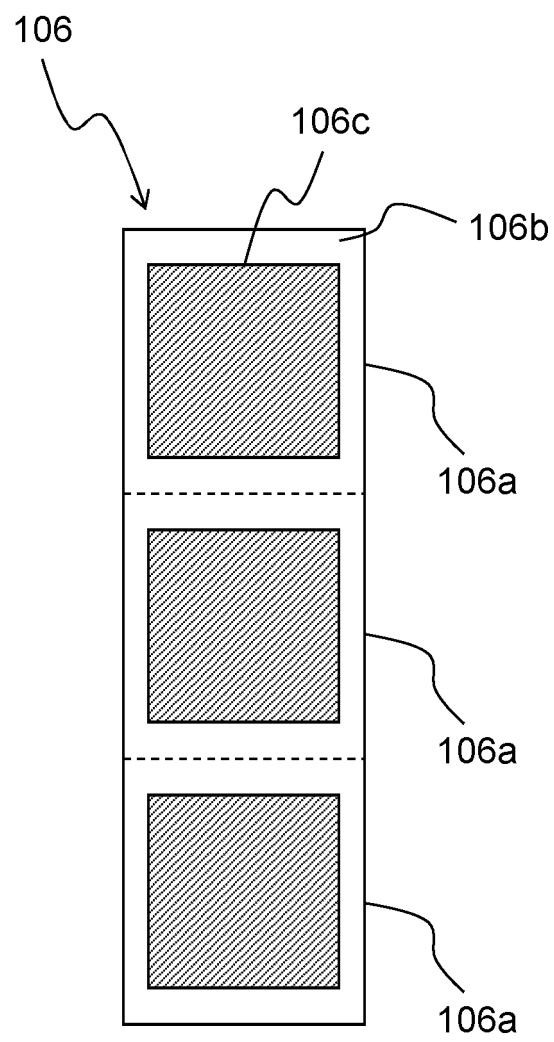


FIG. 3A

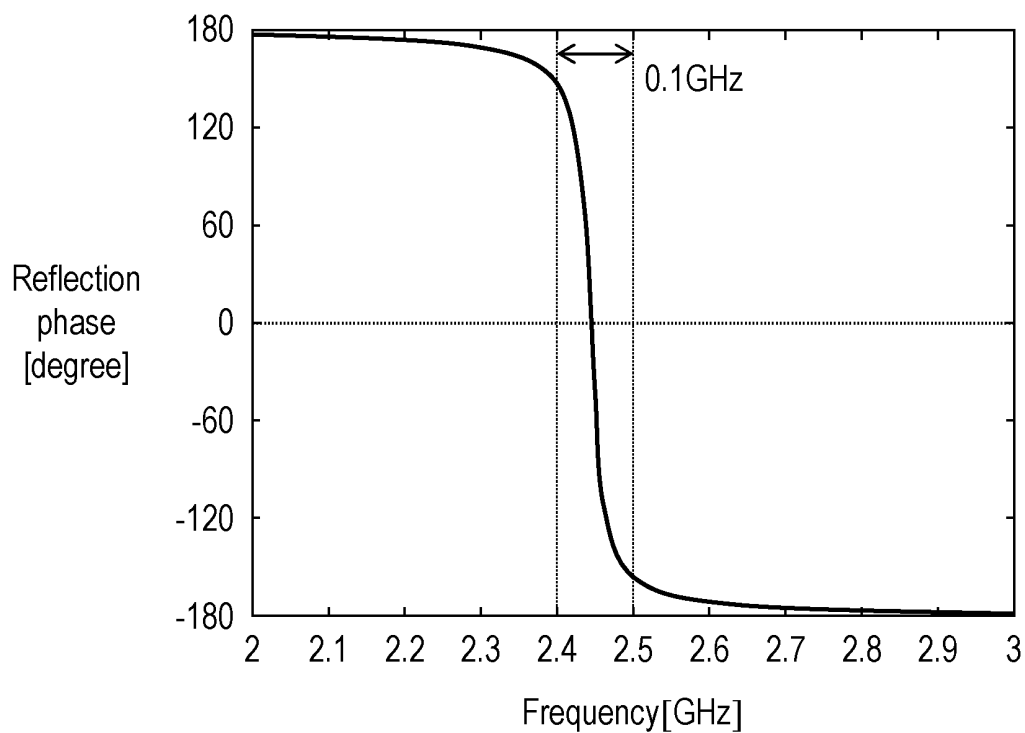


FIG. 3B

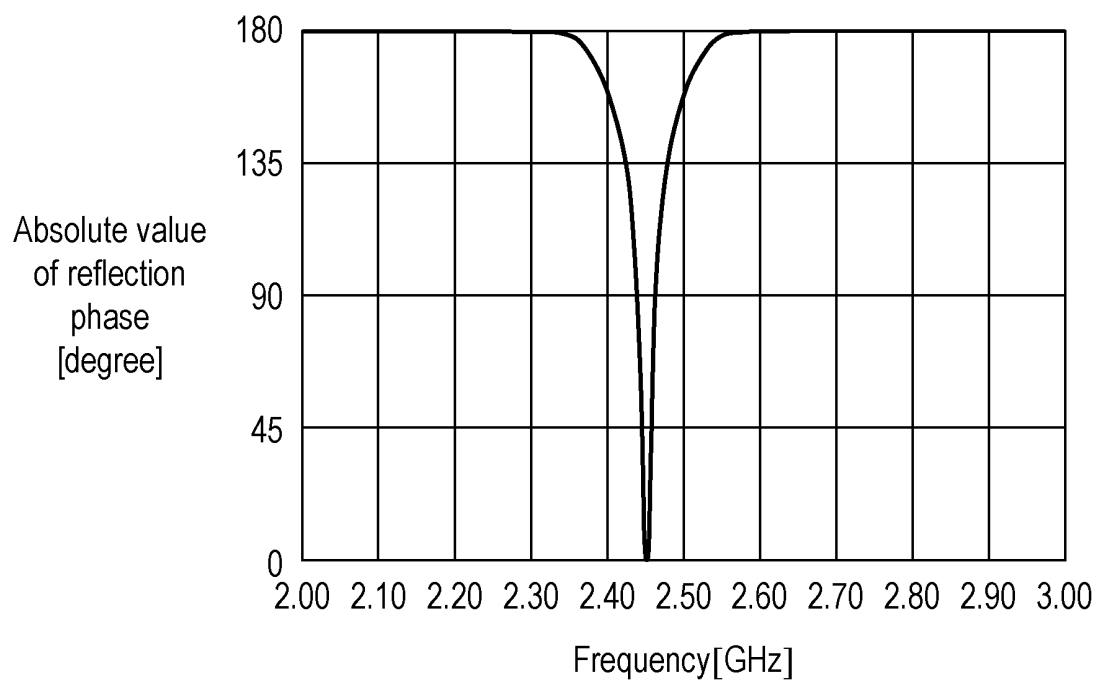


FIG. 4A

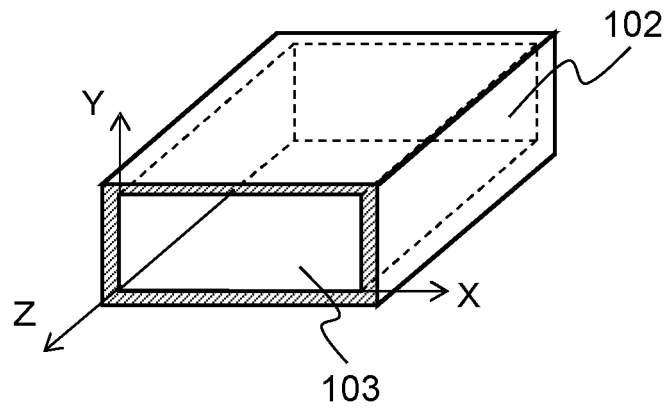


FIG. 4B

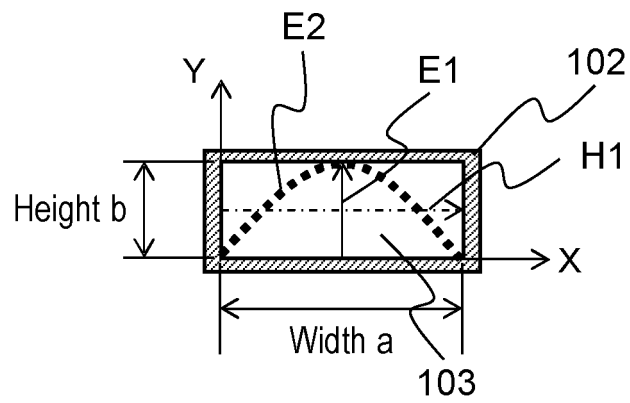


FIG. 4C

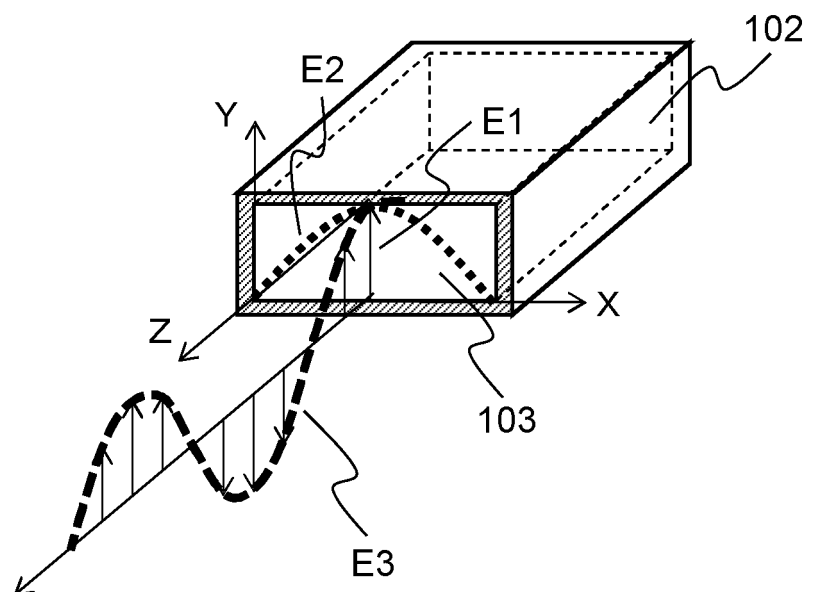


FIG. 5

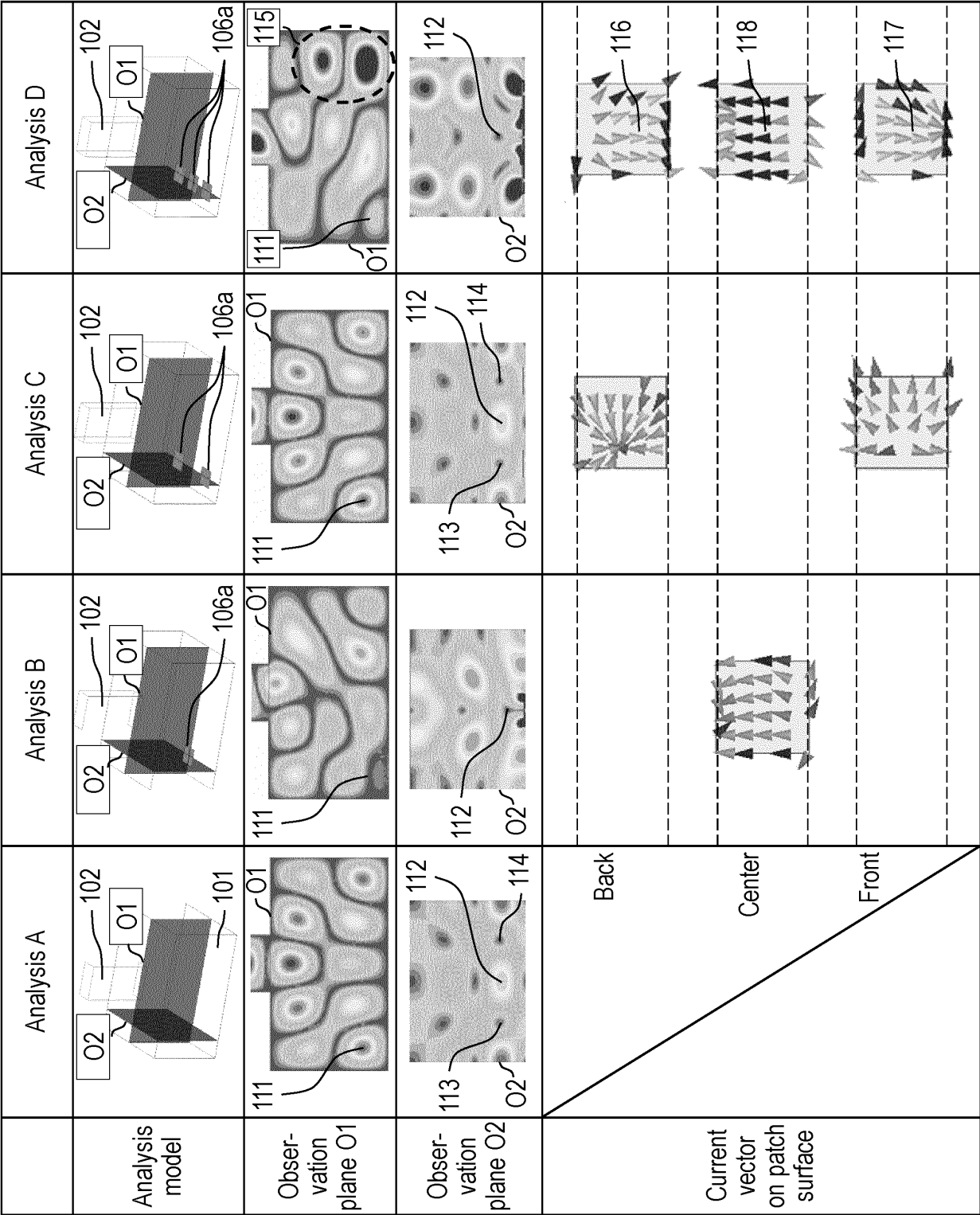


FIG. 6A

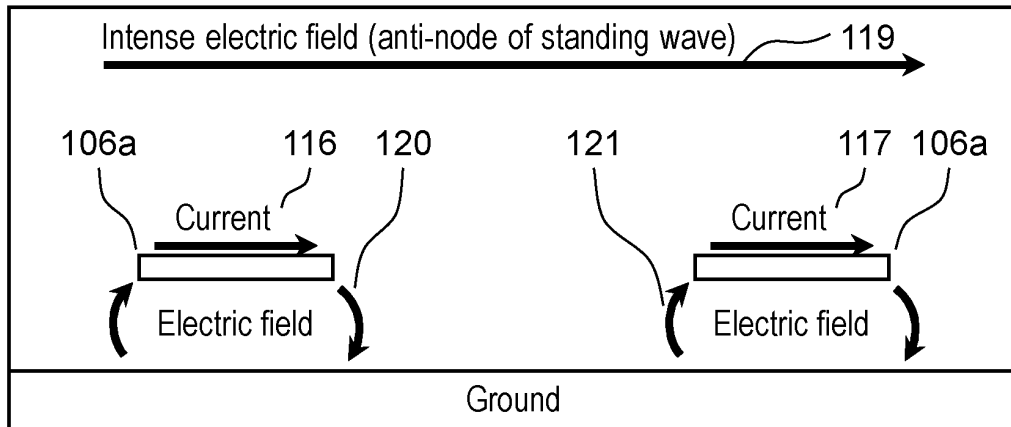


FIG. 6B

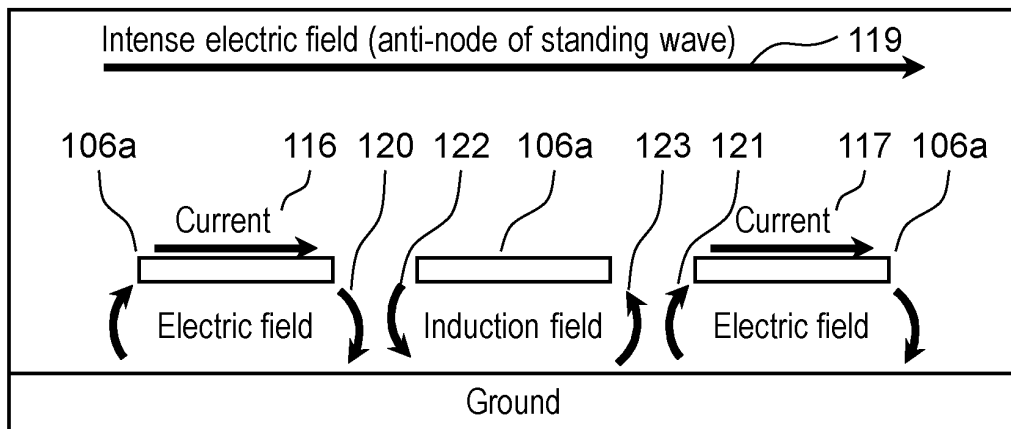


FIG. 6C

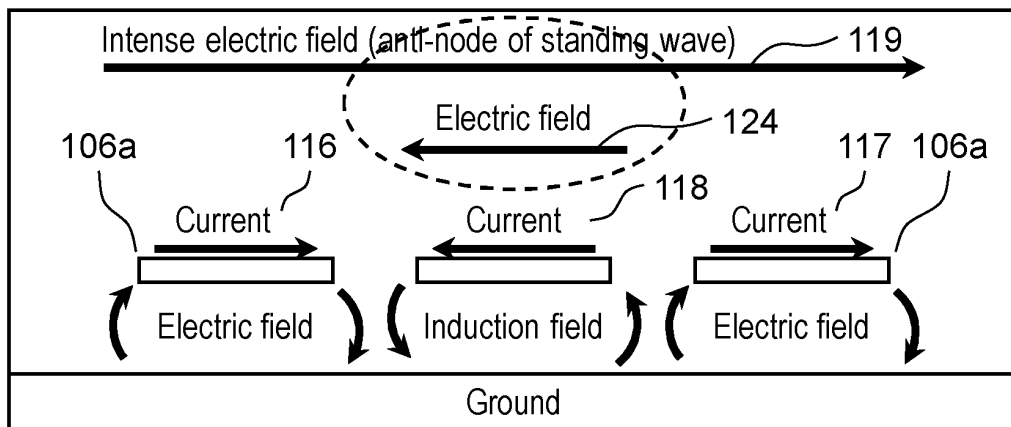


FIG. 7

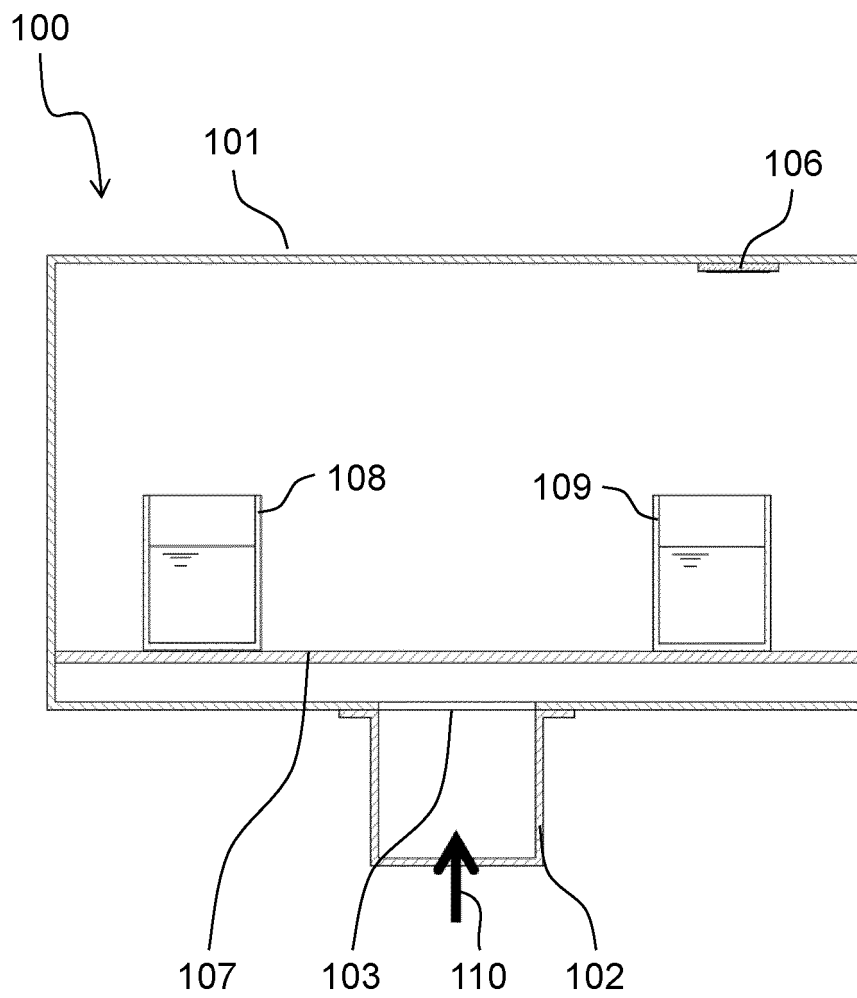


FIG. 8A

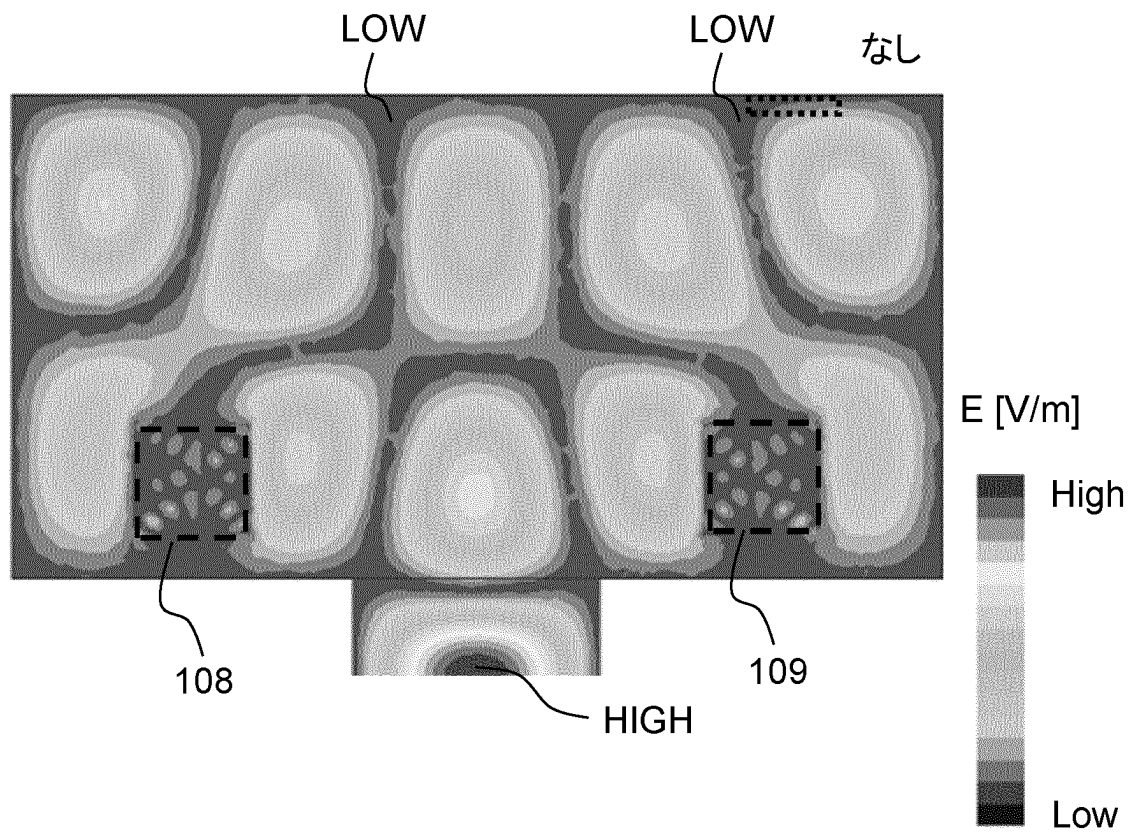


FIG. 8B

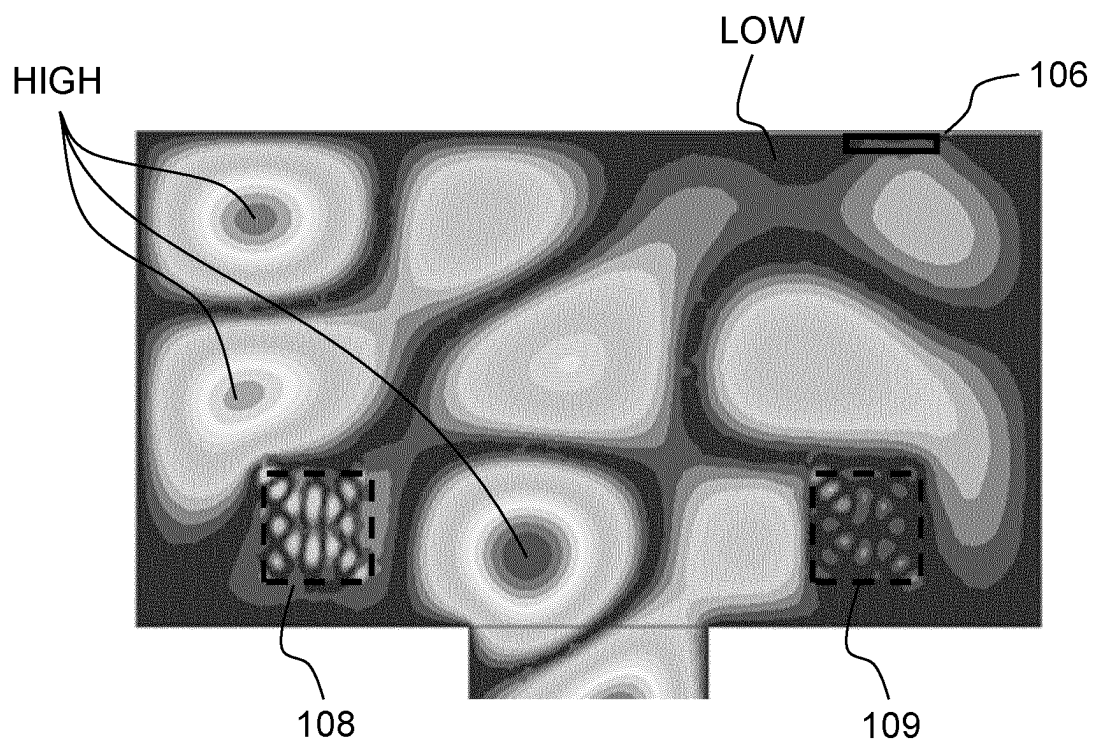


FIG. 9

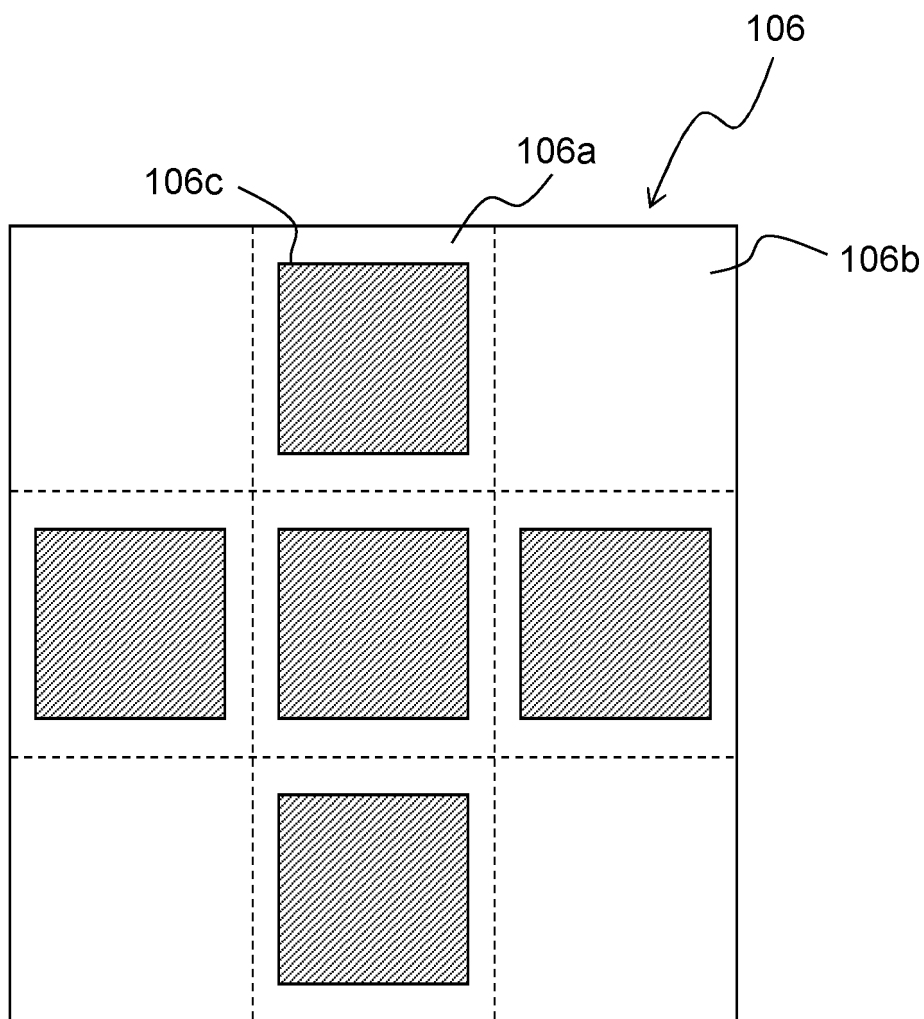


FIG. 10A

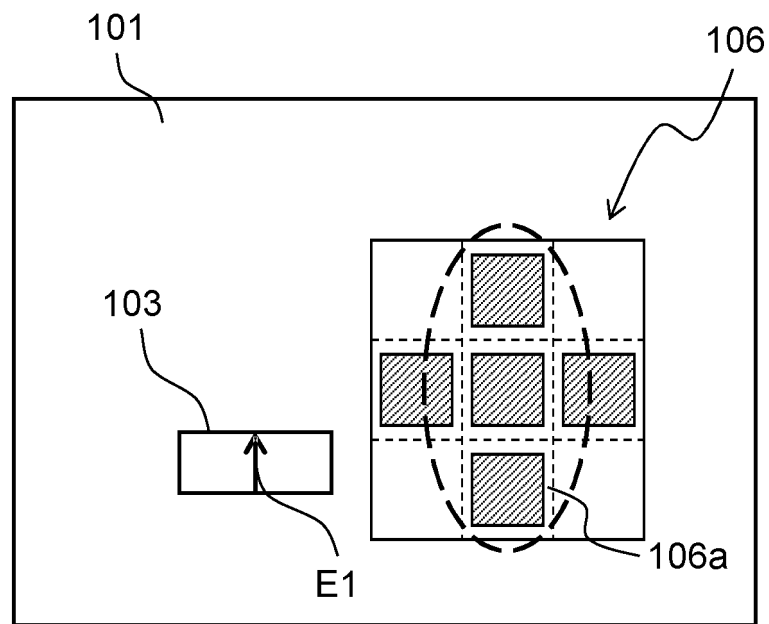


FIG. 10B

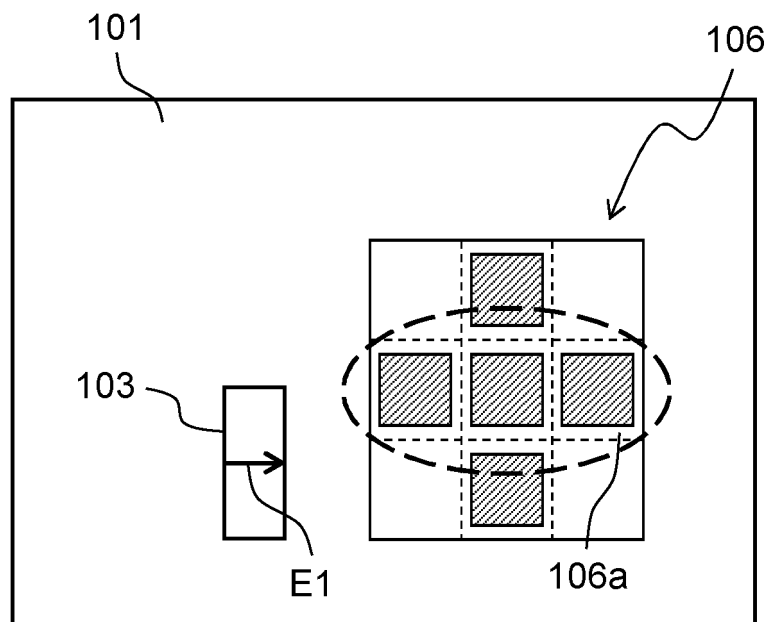


FIG. 11

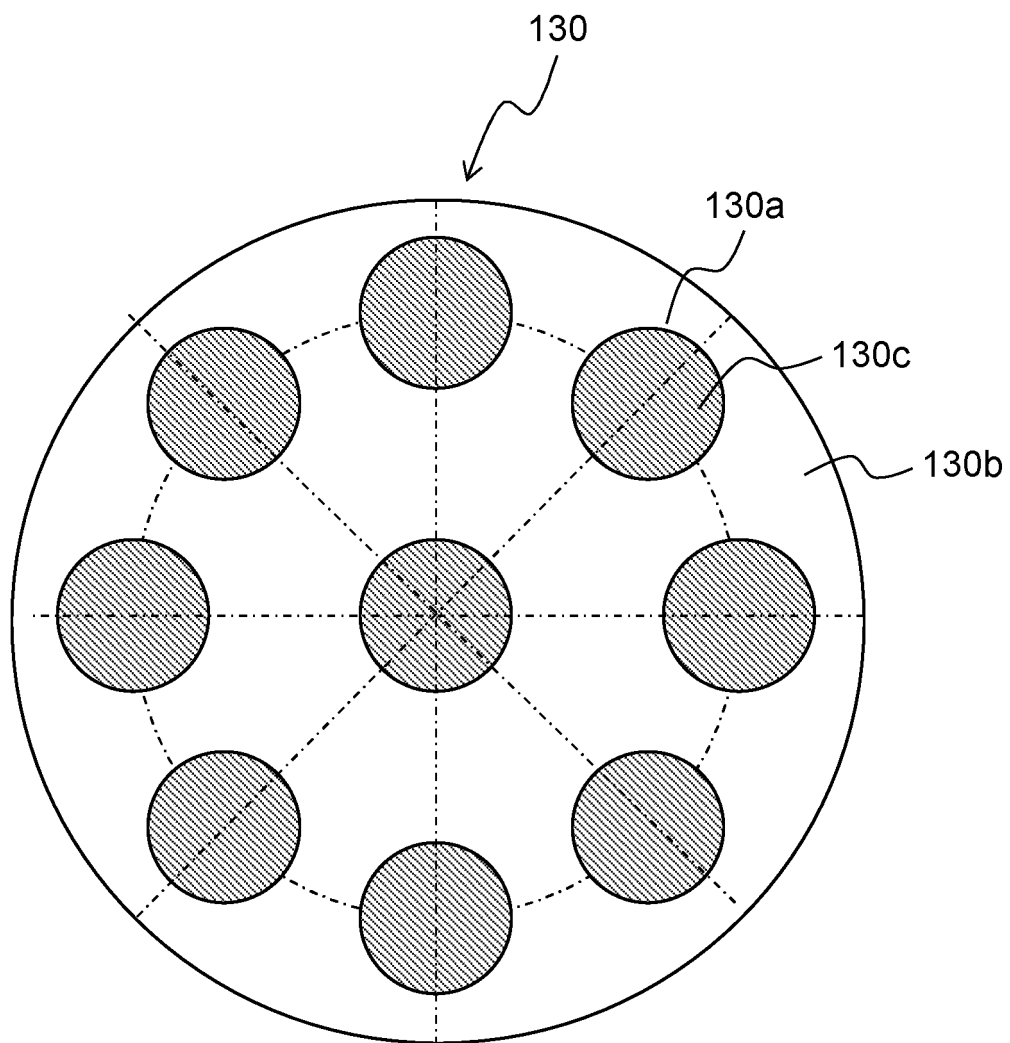


FIG. 12A

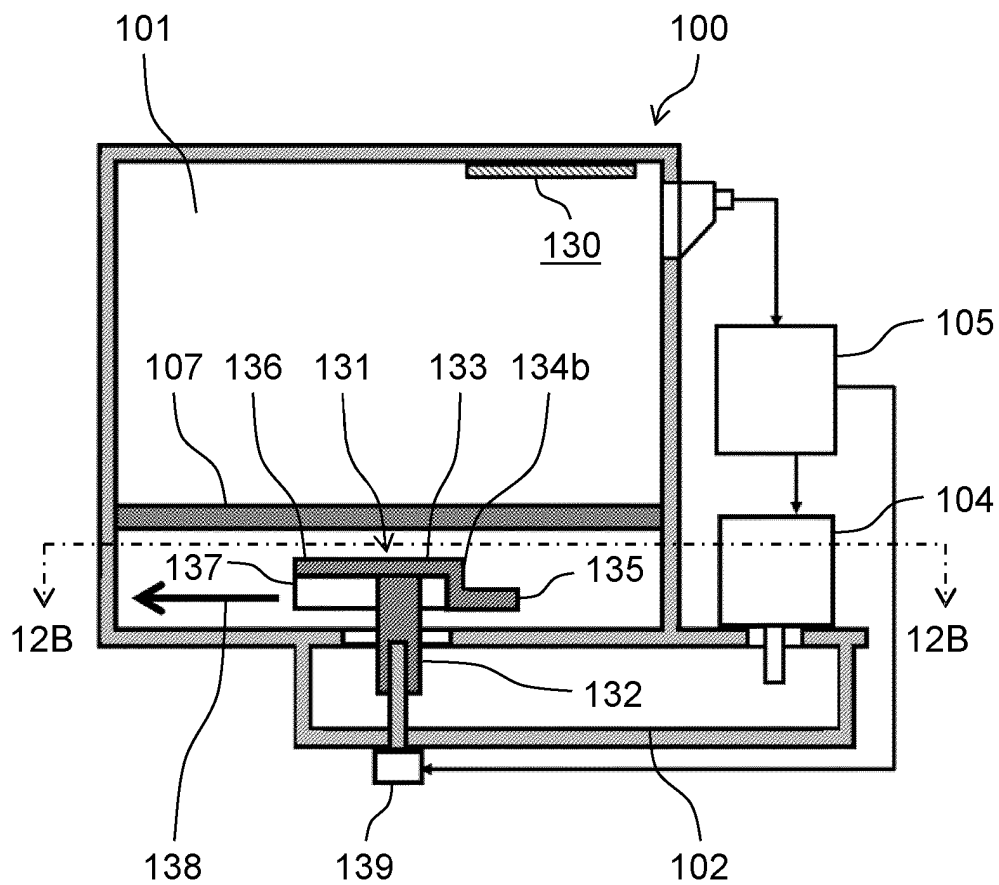


FIG. 12B

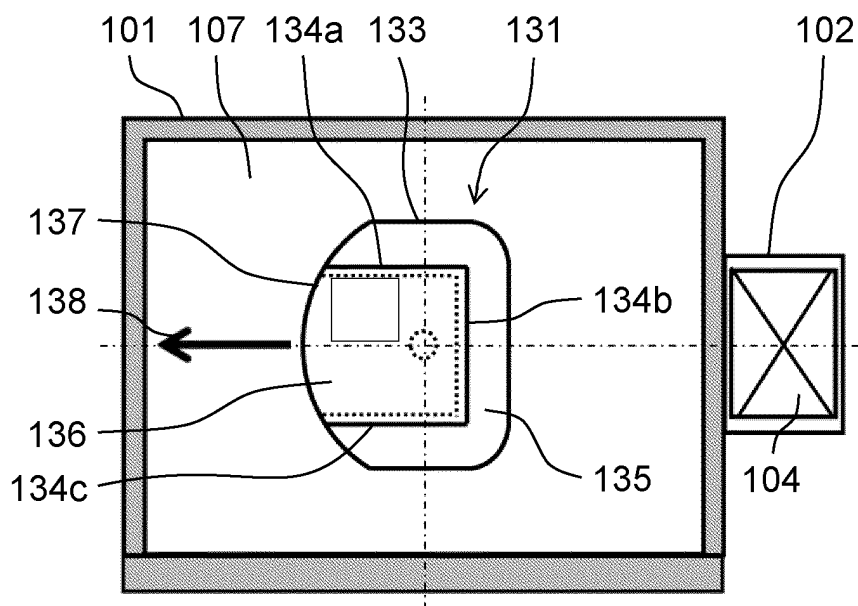


FIG. 13A

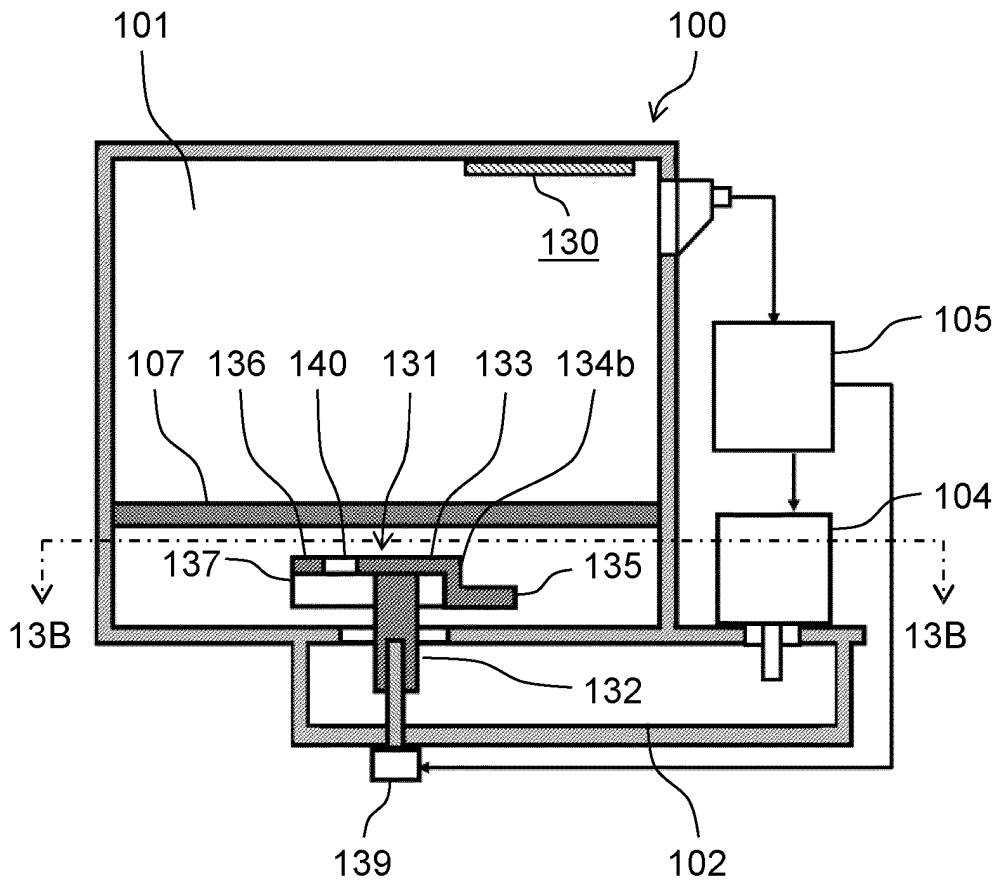


FIG. 13B

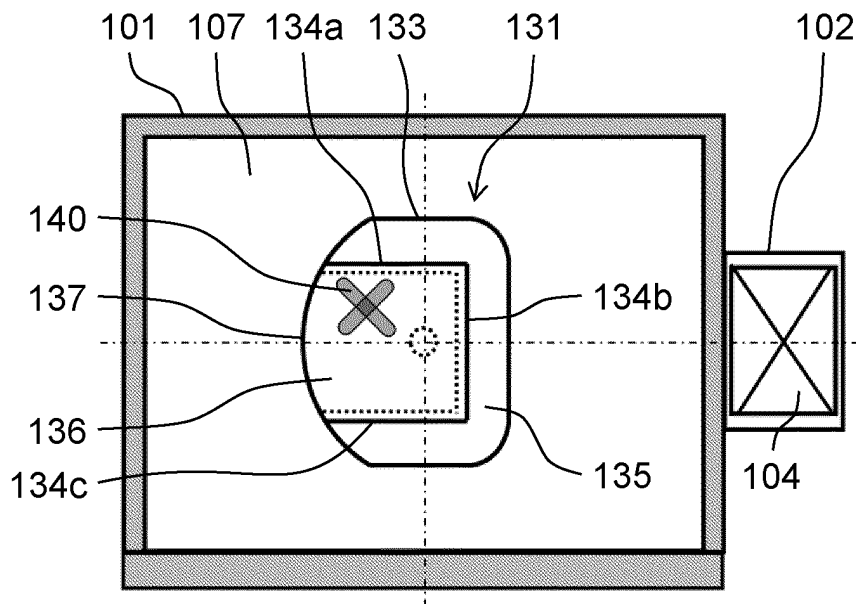


FIG. 14

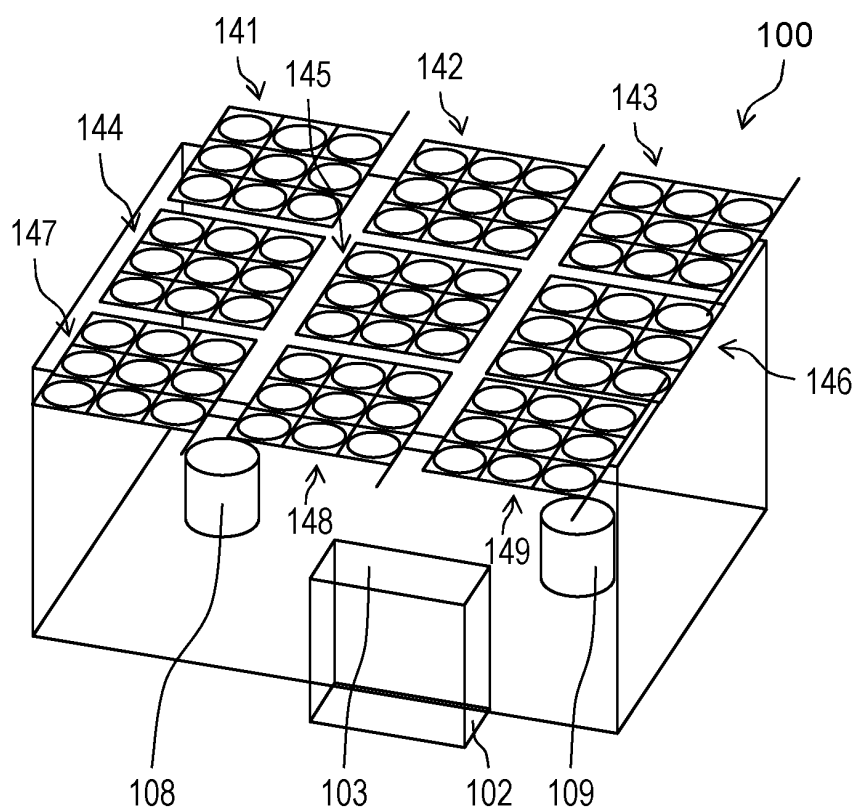


FIG. 15

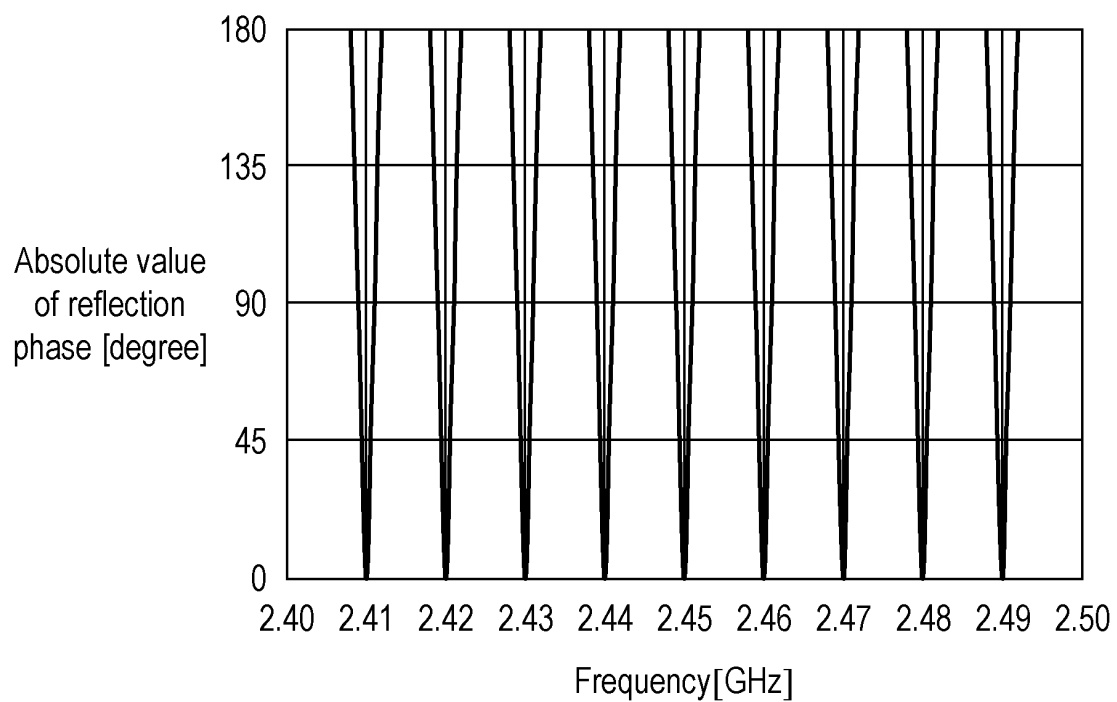
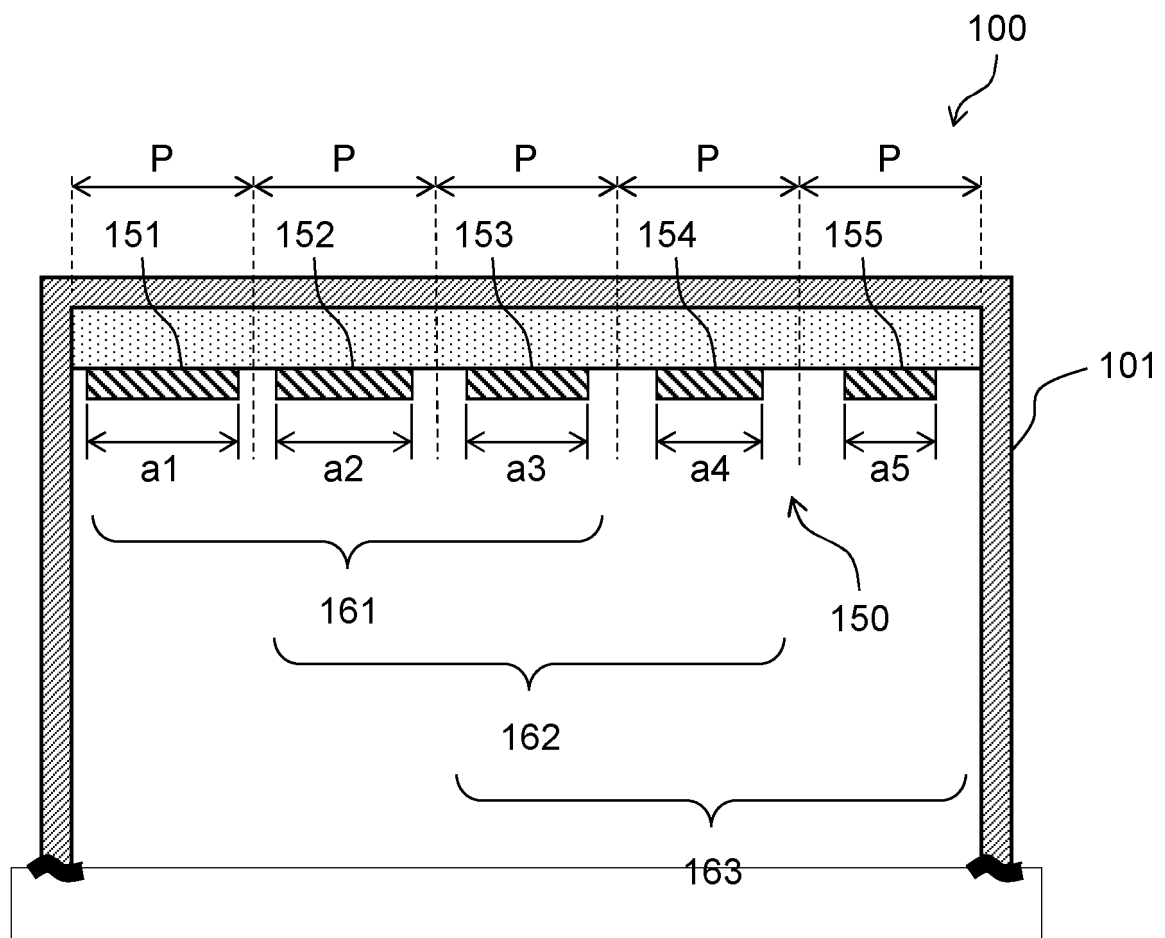


FIG. 16



## INTERNATIONAL SEARCH REPORT

International application No.

PCT/JP2019/035168

## A. CLASSIFICATION OF SUBJECT MATTER

Int.Cl. H05B6/70 (2006.01) i, H05B6/64 (2006.01) i, H05B6/68 (2006.01) i

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)

Int.Cl. H05B6/70, H05B6/64, H05B6/68

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 1971-2019

Registered utility model specifications of Japan 1996-2019

Published registered utility model applications of Japan 1994-2019

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. |
|-----------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------|
| X         | WO 2017/081855 A1 (PANASONIC CORP.) 18 May 2017,                                                                                                                                                                        | 1-4                   |
| Y         | paragraphs [0025]-[0044], fig. 1-5 (Family: none)                                                                                                                                                                       | 5                     |
| A         |                                                                                                                                                                                                                         | 6-9                   |
| Y         | JP 2007-522735 A (TELEFONAKTIEBOLAGET L M ERICSSON (PUBL)) 09 August 2007, paragraphs [0012], [0037], fig. 3 & US 2007/0257853 A1, paragraphs [0010], [0048], fig. 3 & WO 2005/076408 A1 & EP 1723696 A1 & CN 1914766 A | 5                     |



Further documents are listed in the continuation of Box C.



See patent family annex.

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Date of the actual completion of the international search  
01 November 2019 (01.11.2019)Date of mailing of the international search report  
19 November 2019 (19.11.2019)Name and mailing address of the ISA/  
Japan Patent Office  
3-4-3, Kasumigaseki, Chiyoda-ku,  
Tokyo 100-8915, Japan

Authorized officer

Telephone No.

## INTERNATIONAL SEARCH REPORT

International application No.

PCT/JP2019/035168

## C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

| Category* | Citation of document, with indication, where appropriate, of the relevant passages                                                                                             | Relevant to claim No. |
|-----------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------|
| A         | WO 2015/173601 A1 (CENTRE NATIONAL DE LA RECHERCHE SCIENTIFIQUE-CNRS-) 19 November 2015, entire text, all drawings & US 2017/0164429 A1 & EP 3143666 A1 & KR 10-2017-0032229 A | 1-9                   |
| P, X      | WO 2019/009174 A1 (PANASONIC CORP.) 10 January 2019, paragraphs [0026]-[0055], fig. 1-7 (Family: none)                                                                         | 1-5                   |

Form PCT/ISA/210 (continuation of second sheet) (January 2015)

**REFERENCES CITED IN THE DESCRIPTION**

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**Non-patent literature cited in the description**

- **NATIONAL RESEARCH AND DEVELOPMENT AGENCY.** Development of industrial microwave heating system that uses GaN amplifier modules as heat sources. *New Energy and Industrial Technology Development Organization*, 25 January 2016 **[0008]**