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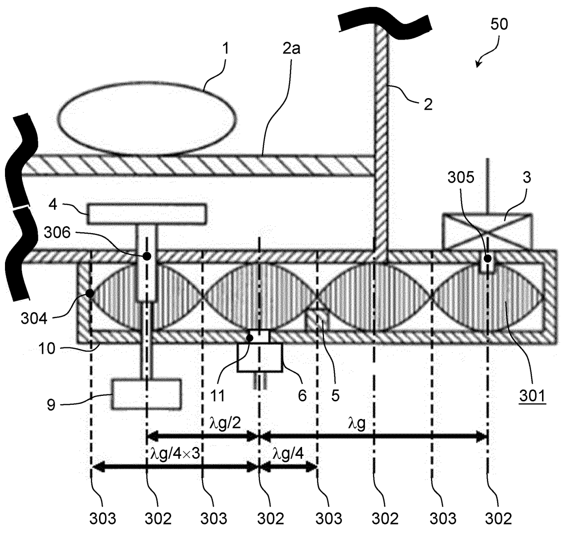
(54) MICROWAVE HEATING DEVICE

(57) Microwave heating device (50) includes: heating chamber (2) to accommodate heating target object (1); magnetron (3) to generate a microwave; waveguide (10) to transmit the microwave generated by the microwave generating unit to heating chamber 2; and directional coupler (6) including a reflected-wave detection unit to detect a part of a reflected wave. Directional coupler (6) is disposed at the position of antinode (302) of standing wave (301) that occurs inside waveguide (10). The present configuration makes possible an increase in detection accuracy of the reflected wave, resulting in more accurate detection of the state of object (1) being heated.

FIG. 21



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Description

TECHNICAL FIELD

[0001] The present disclosure relates to microwave heating devices such as microwave ovens.

BACKGROUND ART

[0002] As a microwave heating device of this type, for example, the device disclosed in Patent Literature 1 has conventionally been known. The conventional microwave heating device includes: a heating chamber to accommodate a heating target object, a microwave generating unit to generate microwaves, a waveguide to cause the microwaves to propagate to the heating chamber. The waveguide is provided with a standing-wave stabilizing part for stabilizing the position of an in-tube standing wave which occurs inside the waveguide. In accordance with the conventional microwave heating device, the standing-wave stabilizing part suppresses the positional disturbance of the in-tube standing wave, which allows the microwave of a desired phase to be continuously emitted into the heating chamber. As a result, the heating target object placed in the heating chamber can be heated uniformly.
[0003] Patent Literature 2 and Patent Literature 3 disclose microwave heating devices which each include a waveguide provided with a directional coupler for detecting a reflected wave, thereby preventing its microwave generating unit from being broken by the reflected wave that returns from its heating chamber to the microwave generating unit.

Citation List

Patent Literature

[0004]

PTL 1: Japanese Patent No. 5816820
PTL 2: Japanese Patent No. 6176540
PTL 3: Japanese Patent No. 3331279

SUMMARY OF THE INVENTION

[0005] The conventional microwave heating device, however, still has room for improvement from the viewpoint of more accurately detecting the state of an object being heated that will change as the heating progresses. In particular, since there is no precedent study focusing on the relationship between detection accuracy of a reflected wave and an in-tube standing wave occurring in a waveguide, it has not been possible to know where a directional coupler is to be best arranged in a waveguide.
[0006] An object of the present disclosure is to improve detection accuracy of a reflected wave, and to provide a microwave heating device capable of more accurately detecting the state of an object being heated.
[0007] A microwave heating device according to an aspect of the present disclosure includes: a heating chamber to accommodate a heating target object; a microwave generating unit to generate a microwave; a waveguide; and a reflected-wave detection unit. The waveguide transmits the microwave generated by the microwave generating unit to the heating chamber. The reflected-wave detection unit is disposed in the vicinity of an antinode of an in-tube standing wave that occurs inside the waveguide, and detects a part of a reflected wave that is a microwave returning from the heating chamber to the microwave generating unit.
[0008] In accordance with the aspect, an increase in detection accuracy of the reflected wave can be achieved, thereby resulting in more accurate detection of the state of the object being heated.

BRIEF DESCRIPTION OF DRAWINGS

[0009]

FIG. 1 is a schematic diagram for illustrating a microwave heating device according to an embodiment of the present disclosure.
FIG. 2 is a schematic diagram for illustrating an example of a first modification of the microwave heating device according to the embodiment.
FIG. 3 is a schematic diagram for illustrating an example of a second modification of the microwave heating device according to the embodiment.

FIG. 4 is a schematic diagram for illustrating an example of a third modification of the microwave heating device according to the embodiment.
FIG. 5 is a perspective view of a directional coupler according to the embodiment.
FIG. 6 is a perspective view of the directional coupler according to the embodiment, in the state in which a printed circuit board has been removed.
FIG. 7 is a plan view of a waveguide according to the embodiment.
FIG. 8 is a circuit configuration diagram of the printed circuit board mounted on the directional coupler according to the embodiment.
FIG. 9 is a diagram for illustrating the principle that a cross opening emits a circularly polarized microwave.
FIG. 10 is a diagram for illustrating the direction and amount of a microwave that propagates through a microstrip line and varies with a lapse of time.
FIG. 11 is a diagram for illustrating the direction and amount of a microwave that propagates through the microstrip line and varies with a lapse of time.
FIG. 12 is a plan view showing an example of a first modification of the microstrip line.
FIG. 13 is a plan view showing an example of a second modification of the microstrip line.
FIG. 14 is a plan view showing an example of a third modification of the microstrip line.
FIG. 15 is a plan view showing an example of a fourth modification of the microstrip line.
FIG. 16 is a plan view showing an example of a fifth modification of the microstrip line.
FIG. 17 is a plan view showing an example of a sixth modification of the microstrip line.
FIG. 18 is a graph showing a relationship among an incident wave, a reflected wave, and the amount of a microwave absorbed by an object being heated, which each vary following the temperature rise of the object being heated.
FIG. 19 is a plan view of a cross-shaped waveguide for evaluating the detection accuracy of a reflected wave.
FIG. 20 is a characteristic diagram showing the detection accuracy of reflected waves which is measured with the cross-shaped waveguide for evaluation.
FIG. 21 is a schematic diagram illustrating the positional relationship between a reflected-wave detection unit and an in-tube standing wave inside a waveguide.

DESCRIPTION OF EMBODIMENTS

(Underlying Knowledge Forming Basis of the Present Disclosure)

[0010] The present inventors have earnestly studied how to detect the state of an object being heated with higher accuracy, and have obtained the following findings.

[0011] A microwave generated by a microwave generating unit propagates, as an incident wave, through a waveguide into a heating chamber. One part of the microwave having propagated into the heating chamber is absorbed by an object being heated, while the other part returns, as a reflected wave, from the heating chamber through the waveguide to the microwave generating unit.

[0012] Microwaves are less prone to be absorbed by ice, but prone to be absorbed by water. Specifically, water can absorb approximately 8000 times (based on a dielectric loss factor) the amount of microwaves that ice can. Microwaves becomes less prone to be absorbed by water as the temperature of the water rises. For this reason, in cases where the heating target object is frozen food, for example, there exists a relationship, as shown in FIG. 18, between a reflected wave and the amount of a microwave absorbed by the object being heated.

[0013] FIG. 18 is a graph showing a relationship among an incident wave, a reflected wave, and the amount of a microwave absorbed by an object being heated, which each vary following the temperature rise of the object being heated. In FIG. 18, the horizontal axis represents the temperature of the object being heated, and the vertical axis represents the signal intensities of the incident wave and the reflected wave. The curves represented by the dotted line, solid line, and dashed-dotted line respectively indicate the incident wave, reflected wave, and the amount of the microwave absorbed by the object being heated. The amount of the microwave absorbed by the object being heated is equal to the difference between the incident wave and the reflected wave.

[0014] As shown in FIG. 18, in early stages of the heating, the amount of the microwave absorbed by the object being heated is small and the amount of the reflected wave is large. As the heating progresses and the ice becomes melted, the amount of the microwave absorbed by the object being heated increases rapidly, while that of the reflected wave decreases rapidly. At the point in time when the ice has completely melted, the amount of the microwave absorbed by the object being heated reaches a maximum, while that of the reflected wave reduces down to a minimum.

[0015] After that, as the temperature of the water rises, the amount of the microwave absorbed by the object being heated gradually decreases, while that of the reflected wave gradually increases. Therefore, for example, detecting the state of the reflected wave reaching a minimum makes it possible to detect finish of thawing the frozen food.

[0016] The present inventors have found that the above relationship holds regardless of the weight and shape of the object being heated, and that it is possible to more accurately detect the state of the object being heated on the basis of changes in the amount of the reflected wave during heating.

[0017] A microwave heating device according to a first aspect of the present disclosure includes: a heating chamber to accommodate a heating target object; a microwave generating unit to generate a microwave; a waveguide; and a reflected-wave detection unit. The waveguide transmits the microwave generated by the microwave generating unit to the heating chamber. The reflected-wave detection unit is disposed in the vicinity of an antinode of an in-tube standing wave that occurs inside the waveguide, and detects a part of a reflected wave that is a microwave returning from the heating chamber to the microwave generating unit.

[0018] In the microwave heating device according to a second aspect of the present disclosure, in addition to the first aspect, the reflected-wave detection unit is disposed between two nodes of the in-tube standing wave such that the reflected-wave detection unit is disposed in the vicinity of the antinode of the in-tube standing wave.

[0019] In the microwave heating device according to a third aspect of the present disclosure, in addition to the second aspect, the reflected-wave detection unit is disposed so as to fail to overlap with the two nodes of the in-tube standing wave such that the reflected-wave detection unit is disposed in the vicinity of the antinode of the in-tube standing wave.

[0020] In the microwave heating device according to a fourth aspect of the present disclosure, in addition to the third aspect, the reflected-wave detection unit is disposed away from the center position between the two nodes of the in-tube standing wave, in the fore-and-aft direction, by not larger than 1/8 of the in-tube wavelength of the in-tube standing wave such that the reflected-wave detection unit is disposed in the vicinity of the antinode of the in-tube standing wave.

[0021] In the microwave heating device according to a fifth aspect of the present disclosure, in addition to the first aspect, the reflected-wave detection unit is disposed away from the terminal end of the waveguide by a distance equal to an odd multiple of 1/4 of the in-tube wavelength of the in-tube standing wave such that the reflected-wave detection unit is disposed in the vicinity of the antinode of the in-tube standing wave.

[0022] The microwave heating device according to a sixth aspect of the present disclosure further includes, in addition to those in the first aspect, a standing-wave stabilizing part to stabilize the position of the in-tube standing wave occurring in the inside the waveguide. The reflected-wave detection unit is disposed away from the standing-wave stabilizing part by a distance equal to an odd multiple of 1/4 of the in-tube wavelength of the in-tube standing wave such that the reflected-wave detection unit is disposed in the vicinity of the antinode of the in-tube standing wave.

[0023] In the microwave heating device according to a seventh aspect of the present disclosure, in addition to the sixth aspect, the standing-wave stabilizing part includes a projection part protruding into the inside of the waveguide.

[0024] In the microwave heating device according to an eighth aspect of the present disclosure, in addition to the sixth aspect, the waveguide includes a bent portion bent in an L-shape, and the standing-wave stabilizing part includes the bent portion.

[0025] In the microwave heating device according to a ninth aspect of the present disclosure, in addition to the first aspect, the microwave generating unit and the waveguide are coupled to each other at a coupling position, and the reflected-wave detection unit is disposed away from the coupling position by a distance equal to an integral multiple of 1/2 of the in-tube wavelength of the in-tube standing wave such that the reflected-wave detection unit is disposed in the vicinity of the antinode of the in-tube standing wave.

[0026] The microwave heating device according to a tenth aspect of the present disclosure further includes, in addition to those in the first aspect, a microwave emitting part configured to emit, into the heating chamber, the microwave transmitted by the waveguide. The microwave emitting part and the waveguide are coupled to each other at a coupling position. The reflected-wave detection unit is disposed away from the coupling position by a distance equal to an integral multiple of 1/2 of the in-tube wavelength of the in-tube standing wave such that the reflected-wave detection unit is disposed in the vicinity of the antinode of the in-tube standing wave.

[0027] In the microwave heating device according to an eleventh aspect of the present disclosure, in addition to the first aspect, the reflected-wave detection unit includes: an opening disposed in the waveguide, and a coupling line facing the opening. The opening is disposed in the vicinity of the antinode of the in-tube standing wave.

[0028] In the microwave heating device according to a twelfth aspect of the present disclosure, in addition to the eleventh aspect, the opening is disposed at a position failing to intersect the tube axis of the waveguide in a plan view, and includes: a first elongated hole, and a second elongated hole, the first and second elongated holes crossing each other at an opening-cross portion. The opening-cross portion is disposed in the vicinity of the antinode of the in-tube standing wave.

[0029] Hereinafter, microwave heating devices according to an embodiment of the present disclosure will be described with reference to the drawings.

(Exemplary Embodiments)

[0030] FIG. 1 is a schematic diagram for illustrating microwave heating device 50 according to the embodiment of the present disclosure. As shown in FIG. 1, microwave heating device 50 includes heating chamber 2 to accommodate heating target object 1, magnetron 3, and waveguide 10. Magnetron 3 is an example of a microwave generating unit that generates microwaves. Waveguide 10 causes the microwaves generated by magnetron 3 to propagate to heating chamber 2.

[0031] Heating target object 1 is frozen food, for example. Heating chamber 2 is configured with a rectangular parallelepiped casing, for example. Heating chamber 2 is provided with loading stand 2a on which heating target object 1 is placed. Loading stand 2a is configured including a material, such as glass or ceramic, through which microwaves can be easily transmitted.

[0032] Waveguide 10 is a square waveguide having a cross section formed in a rectangular shape. Antenna 4 is disposed below loading stand 2a. The microwave having propagated through waveguide 10 is emitted into the inside of heating chamber 2 by antenna 4.

[0033] The microwave produces an in-tube standing wave of the microwave in the inside of waveguide 10, in the transmission direction of the microwave proceeding from magnetron 3 toward antenna 4. FIG. 1 schematically illustrates the in-tube standing wave produced in the inside of waveguide 10. In-tube wavelength λg in waveguide 10 is determined from the oscillation frequency of the magnetron 3 and the shape of waveguide 10.

[0034] The in-tube standing wave has a node and antinode that repeatedly appears every 1/2 of in-tube wavelength λg, in the longitudinal direction of waveguide 10. A node always appears at a terminal end, in the transmission direction of the microwave, of the waveguide 10. An antinode always appears at a portion from which magnetron 3 emits the microwave.

[0035] Waveguide 10 is provided with standing-wave stabilizing part 5 for stabilizing the position of an in-tube standing wave occurring inside waveguide 10. In accordance with the present embodiment, standing-wave stabilizing part 5 is a projection part that is configured to protrude toward the inside of waveguide 10 and thereby to make waveguide 10 locally narrower.

[0036] In the inside of waveguide 10, standing-wave stabilizing part 5 matches the impedance in the vicinity of magnetron 3 to the impedance in the vicinity of heating chamber 2. Standing-wave stabilizing part 5 is disposed away from the waveguide 10's terminal end that is positioned in the transmission direction of the microwave, by a distance equal to an integral multiple of 1/2 of in-tube wavelength λg. With this configuration, standing-wave stabilizing part 5 fixes a node of the in-tube standing wave in the vicinity of standing-wave stabilizing part 5.

[0037] On a wall surface (Wide Plane) of waveguide 10, directional coupler 6 is disposed which has both the function of an incident-wave detection unit and the function of a reflected-wave detection unit. The incident-wave detection unit detects a part of an incident wave which is a microwave propagating from magnetron 3 to heating chamber 2. The reflected-wave detection unit detects a part of a reflected wave which is a microwave returning from heating chamber 2 to magnetron 3.

[0038] Directional coupler 6 is disposed closer to heating chamber 2 than standing-wave stabilizing part 5. Specifically, directional coupler 6 and standing-wave stabilizing part 5 are disposed and separated from each other in the transmission direction (left-right direction in FIG. 1) of the microwave, by a distance equal to an odd multiple (1-fold in the present embodiment) of 1/4 of in-tube wavelength λg of the in-tube standing wave. Directional coupler 6 is disposed between standing-wave stabilizing part 5 and antenna 4.

[0039] Directional coupler 6 individually detects detection signal 6a and detection signal 6b in accordance with the incident wave and the reflected wave, respectively, and transmits detection signal 6a and detection signal 6b to controller 7. The specific configuration of directional coupler 6 will be described later in detail.

[0040] Controller 7 receives signal 7a in addition to detection signals 6a and 6b. Signal 7a includes signals regarding: a heating condition that is set by means of an input unit (not shown) of microwave heating device 50, and the weight and vapor amount of heating target object 1 that are detected with sensors (not shown).

[0041] Controller 7 controls drive power supply 8 and motor 9, in accordance with signal 7a and detection signals 6a and 6b. Drive power supply 8 supplies, to magnetron 3, electric power for generating microwaves. Motor 9 rotates antenna 4. In this way, microwave heating device 50 heats heating target object 1 accommodated in heating chamber 2, by means of the microwave supplied to heating chamber 2.

[0042] In the present embodiment, directional coupler 6 is disposed closer to heating chamber 2 than standing-wave stabilizing part 5. With this configuration, the influence of standing-wave stabilizing part 5 on directional coupler 6 is reduced. This allows more accurate detection of the state of object 1 being heated. As a result, for example, it is possible to accurately grasp the thawing state of frozen food. By controlling the amount of heating in accordance with the state, it is also possible to shorten the thawing time.

[0043] In the present embodiment, directional coupler 6 and standing-wave stabilizing part 5 are disposed and separated from each other in the transmission direction of the microwave, by a distance equal to an odd multiple of 1/4 of in-tube wavelength λg of the in-tube standing wave. With this configuration, it is possible to dispose directional coupler 6 in the vicinity of an antinode. This makes it possible to increase the amount of the reflected wave that directional coupler 6 receives, resulting in improved accuracy of the detection of the reflected wave. As a result, the state of object 1 being heated can be detected more accurately.

[0044] The positions of directional coupler 6 and standing-wave stabilizing part 5 in the width direction (depth direction in FIG. 1) of waveguide 10 are not particularly limited. It is sufficient for directional coupler 6 and standing-wave stabilizing part 5 to be disposed and separated from each other by a distance approximately equal to an odd multiple of 1/4 of in-tube wavelength λg.

[0045] In cases either where the temperature of heating target object 1 is high at the start of heating or where the weight of heating target object 1 is heavy, the amount of the reflected wave varies not so much. For this reason, there are cases where it is difficult to judge the state of the reflected wave reducing down to a minimum.

[0046] In the present embodiment, directional coupler 6 has both the function of the incident-wave detection unit and the function of the reflected-wave detection unit. With this configuration, on the basis of the incident wave and reflected wave detected by directional coupler 6, the amount of the microwave absorbed by object 1 being heated can be estimated more accurately. For example, by detecting a change in reflectance obtained by dividing the amount of the reflected wave by the amount of the incident wave, it becomes easy to judge the state of the reflected wave reducing down to a minimum. As a result, the state of object 1 being heated can be detected more accurately.

[0047] In the present embodiment, directional coupler 6 has both the function of the incident-wave detection unit and the function of the reflected-wave detection unit. However, the present disclosure is not limited to this. The incident-wave detection unit and the reflected-wave detection unit may be disposed separately. The incident-wave detection unit may be disposed closer to magnetron 3 than standing-wave stabilizing part 5.

[0048] In the present embodiment, one directional coupler 6 is disposed closer to heating chamber 2 than standing-wave stabilizing part 5. However, the present disclosure is not limited to this. FIG. 2 is a schematic diagram for illustrating an example of a first modification of microwave heating device 50. As in the case of FIG. 1, FIG. 2 also schematically illustrates an in-tube standing wave occurring in the inside of waveguide 10.

[0049] As shown in FIG. 2, microwave heating device 50 according to the example of the first modification further includes, in addition to directional coupler 6, directional coupler 60 having the same configuration as that of directional coupler 6. That is, directional coupler 60 includes a second reflected-wave detection unit that has the same configuration as that of the reflected-wave detection unit provided in directional coupler 6. Directional coupler 60 is disposed closer to magnetron 3 than standing-wave stabilizing unit 5.

[0050] In this configuration, the second reflected-wave detection unit as well can detect a part of the reflected wave that passes through standing-wave stabilizing part 5 and returns to magnetron 3. With this configuration, for example, in cases where the amount of the reflected wave is excessively large, it is possible to halt magnetron 3 and thereby to prevent magnetron 3 from being broken.

[0051] In the present embodiment, standing-wave stabilizing part 5 is configured with the projection part that protrudes toward the inside of waveguide 10. However, standing-wave stabilizing part 5 is not limited to the present embodiment, as long as it can stabilize the position of the in-tube standing wave by locally narrowing waveguide 10 and thereby disturbing the propagation of the microwave.

[0052] FIG. 3 is a schematic diagram for illustrating an example of a second modification of microwave heating device 50. As in the cases of FIGS. 1 and 2, FIG. 3 also schematically illustrates an in-tube standing wave occurring in the inside of waveguide 10. As shown in FIG. 3, waveguide 10 includes bent portion 10b bent in an L-shape.

[0053] In this case, the cross-sectional area of bent portion 10b indicated by the dotted line in FIG. 3 is larger than the cross-sectional area of the other portion of waveguide 10. For this reason, a node of the in-tube standing wave is prone to be fixed at the center (center of the dotted line in FIG. 3) of bent portion 10b. In the example of the second modification, bent portion 10b constitutes standing-wave stabilizing part 5.

[0054] Waveguide 10 shown in FIG. 1 is a square waveguide that has a uniform cross-sectional area, except for the portion where standing-wave stabilizing part 5 is disposed. However, the present disclosure is not limited to this. FIG. 4 is a schematic diagram for illustrating an example of a third modification of microwave heating device 50. As in the cases of FIGS. 1 to 3, FIG. 4 also schematically illustrates an in-tube standing wave occurring in the inside of waveguide 10.

[0055] As shown in FIG. 4, in the example of the third modification, waveguide 10 is a square waveguide whose cross-sectional area gradually decreases at greater distances away from magnetron 3 toward heating chamber 2. Waveguide 10 does not include any locally narrowed section other than the portion provided with standing-wave stabilizing part 5. Therefore, waveguide 10 according to the example of the third modification can achieve the same advantages as those of waveguide 10 shown in FIG. 1.

[0056] Standing-wave stabilizing part 5 shown in FIG. 1 is configured with one constituent element. However, standing-wave stabilizing part 5 may be configured with a plurality of constituent elements. In this case, it is sufficient for directional coupler 6 to be disposed closer to heating chamber 2 than the constituent element that is the closest, of the constituent elements of standing-wave stabilizing part 5, to heating chamber 2.

[0057] In the present embodiment, motor 9 rotates antenna 4. However, the present disclosure is not limited to this. For example, antenna 4 may be an opening formed so as to emit the microwave having propagated through waveguide 10 into heating chamber 2, as a circularly polarized microwave.

[0058] Next, the configuration of directional coupler 6 is described. FIG. 5 is a perspective view of directional coupler

6. FIG. 6 is a perspective view of directional coupler 6 in the state in which printed circuit board 12 has been removed. FIG. 7 is a plan view of waveguide 10. FIG. 8 is a circuit configuration diagram of printed circuit board 12 mounted on directional coupler 6.

[0059] In FIGS. 1 to 4, directional coupler 6 is illustrated as being disposed on the bottom wall of waveguide 10. However, in FIGS. 5 and 6, directional coupler 6 is illustrated as being disposed on the upper wall of waveguide 10 for easy understanding. In the present embodiment, the cross section orthogonal to tube axis L1 of waveguide 10 has a rectangular shape. Tube axis L1 is the center axis of waveguide 10, in the direction of the width.

[0060] Directional coupler 6 includes cross opening 11, printed circuit board 12, and support part 14. Cross opening 11 is an X-shaped opening disposed in wide plane 10a of waveguide 10. Printed circuit board 12 is disposed outside waveguide 10 so as to face cross opening 11. Support part 14 supports printed circuit board 12 on an outer surface of waveguide 10.

[0061] As shown in FIG. 7, cross opening 11 is disposed at a position failing to intersect tube axis L1 of waveguide 10, in a plan view. Opening-center portion 11c of cross opening 11 is disposed away from tube axis L1 of waveguide 10 by dimension D1 in a plan view. Dimension D1 is, for example, 1/4 of the width of waveguide 10. Cross opening 11 emits microwaves propagating through waveguide 10, as circularly polarized microwaves, toward printed circuit board 12.

[0062] The opening shape of cross opening 11 is determined in accordance with conditions including: the width and height of waveguide 10, the power levels and frequency bands of microwaves propagating through waveguide 10, and the power levels of circularly polarized microwaves emitted from cross opening 11.

[0063] For example, in the case where the width and height of waveguide 10 are respectively 100 mm and 30 mm, the wall thickness of waveguide 10 is 0.6 mm, the maximum power level of the microwave propagating through waveguide 10 is 1000 W, the frequency band is 2450 MHz, and the maximum power level of the circularly polarized microwave emitted from cross opening 11 is approximately 10 mW, length 11w and width 11d of cross opening 11 are set to 20 mm and 2 mm, respectively.

[0064] As shown in FIG. 8, cross opening 11 includes: first elongated hole 11e, and second elongated hole 11f which cross each other. Opening-center portion 11c of cross opening 11 coincides with an opening-cross portion where first elongated hole 11e crosses second elongated hole 11f. Cross opening 11 is formed to have line symmetry with respect to perpendicular line L2. Perpendicular line L2 is orthogonal to tube axis L1, and passes through opening-center portion 11c.

[0065] In the embodiment, first elongated hole 11e and second elongated hole 11f cross each other at an angle of 90 degrees. However, the present disclosure is not limited to this. First elongated hole 11e and second elongated hole 11f may cross each other at an angle of either 60 degrees or 120 degrees.

[0066] In the case where opening-center portion 11c of cross opening 11 is disposed at a position at which it is superposed on tube axis L1 in a plan view, the electric field reciprocates along the transmission direction of the microwave, without rotating. In this case, cross opening 11 emits a linearly polarized microwave.

[0067] In the case where opening-center portion 11c is even slightly out of tube axis L1, the electric field will rotate. However, in the case where opening-center portion 11c is close to tube axis L1 (as dimension D1 is closer to 0 [zero] mm), a distorted rotating electric field is generated. In this case, cross opening 11 emits an elliptically polarized microwave.

[0068] According to the embodiment, dimension D1 is set equal to approximately 1/4 of the width of waveguide 10. In this case, an substantially-perfect circular rotating electric field is generated. Cross opening 11 emits an substantially-perfect circularly polarized microwave. This allows the rotation direction of the circularly polarized microwave to be more distinct. As a result, the incident wave and the reflected wave can be separately detected with high accuracy.

[0069] Printed circuit board 12 has board rear surface 12b facing cross opening 11, and board front surface 12a opposite to board rear surface 12b. Board front surface 12a includes a copper foil (not shown), an example of a microwave reflecting member, that is formed to cover the whole of board front surface 12a. It is the copper foil that prevents the circularly polarized microwaves emitted from cross opening 11 from passing through printed circuit board 12.

[0070] As shown in FIG. 8, microstrip line 13, an example of a coupling line, is disposed on board rear surface 12b. Microstrip line 13 is configured with a transmission line with a characteristic impedance of approximately 50 Ω, for example. Microstrip line 13 is disposed so as to surround opening-center portion 11c of cross opening 11.

[0071] Hereinafter, effective length λ_{re} of microstrip line 13 will be described. Effective length λ_{re} of microstrip line 13 is expressed as the following equation, where "w" is the width of microstrip line 13, "h" is the thickness of printed circuit board 12, "c" is the velocity of light, "f" is the frequency of an electromagnetic wave, and "ε_r" is the relative permittivity of the printed circuit board. Effective length λ_{re} equals the wavelength of an electromagnetic wave propagating through microstrip line 13.

[Equation 1]

$$\lambda_{re} = \frac{c}{f \cdot \sqrt{\varepsilon_{re}}}$$

$$\varepsilon_{re} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2} \cdot \frac{1}{\sqrt{(1 + 10h/w)}}$$

[0072] Specifically, microstrip line 13 includes: first transmission line 13a, and second transmission line 13b. First transmission line 13a has first straight-line portion 13aa which is an example of a first intersecting-line portion. First straight-line portion 13aa intersects first elongated hole 11e at a position farther away from tube axis L1 than opening-center portion 11c, in a plan view. First straight-line portion 13aa extends away from tube axis L1 as approaching perpendicular line L2.

[0073] Second transmission line 13b has second straight-line portion 13ba which is an example of a second intersecting-line portion. Second straight-line portion 13ba intersects second elongated hole 11f at a position farther away from tube axis L1 than opening-center portion 11c, in a plan view. Second straight-line portion 13ba extends away from tube axis L1 as approaching perpendicular line L2. First straight-line portion 13aa and second straight-line portion 13ba are disposed to have line symmetry with respect to perpendicular line L2.

[0074] First transmission line 13a and second transmission line 13b are coupled to each other at a position that is outside rectangular region E1 and is farther away from tube axis L1 than rectangular region E1, in a plan view. First straight-line portion 13aa intersects first elongated hole 11e at a position that is closer to opening-end portion 11ea than opening-center portion 11c, in a plan view.

[0075] First straight-line portion 13aa intersects first elongated hole 11e at right angles, in a plan view. Second straight-line portion 13ba intersects second elongated hole 11f at a position that is closer to opening-end portion 11fa than opening-center portion 11c, in a plan view. Second straight-line portion 13ba intersects second elongated hole 11f at right angles, in a plan view.

[0076] One end of first transmission line 13a and one end of second transmission line 13b are coupled to each other at outside the region that is superposed on cross opening 11, in a plan view. One end of first straight-line portion 13aa is coupled to one end of second straight-line portion 13ba at outside rectangular region E1 that circumscribes cross opening 11.

[0077] First coupling point P1 is a point where first straight-line portion 13aa and first elongated hole 11e intersect each other in a plan view. Second coupling point P2 is a point where second straight-line portion 13ba and second elongated hole 11f intersect each other in a plan view. A straight line that connects first coupling point P1 and second coupling point P2 is defined as virtual straight line L3. In the present embodiment, the sum of a line distance of first transmission line 13a further away from tube axis L1 than virtual straight line L3 and a line distance of second transmission line 13b further away from tube axis L1 than virtual straight line L3, is set equal to 1/4 of effective length λ_{re}.

[0078] In a plan view, a line that passes through opening-center portion 11c and is parallel to tube axis L1 is defined as parallel line L4. In the present embodiment, the sum of a line distance of first transmission line 13a further away from tube axis L1 than parallel line L4 and a line distance of second transmission line 13b further away from tube axis L1 than parallel line L4, is set equal to 1/2 of effective length λ_{re}.

[0079] First transmission line 13a includes third straight-line portion 13ab that couples the other end of first straight-line portion 13aa to first output part 131. First straight-line portion 13aa and third straight-line portion 13ab are coupled to each other so as to make an obtuse angle (e.g. 135 degrees).

[0080] Second transmission line 13b includes fourth straight-line portion 13bb that couples the other end of second straight-line portion 13ba to second output part 132. Second straight-line portion 13ba and fourth straight-line portion 13bb are coupled to each other so as to make an obtuse angle (e.g. 135 degrees). Third straight-line portion 13ab and fourth straight-line portion 13bb are disposed in parallel with perpendicular line L2.

[0081] First output part 131 and second output part 132 are disposed outside support part 14 (see FIGS. 5 and 6) in a plan view. To first output part 131, first detector circuit 15 is coupled. First detector circuit 15 detects the level of a microwave signal, and outputs the detected level of the microwave signal as a control signal. To second output part 132, second detector circuit 16 is coupled. Second detector circuit 16 detects the level of a microwave signal, and outputs the detected level of the microwave signal as a control signal.

[0082] In the present embodiment, each of first detector circuit 15 and second detector circuit 16 includes a smoothing circuit (not shown) that is configured including a chip resistor and a Schottky diode. First detector circuit 15 rectifies a microwave signal fed from first output part 131, and converts the rectified microwave signal into a direct-current voltage. The thus-converted direct-current voltage is fed to first detection output unit 18. First detection output unit 18 transmits, to controller 7, detection signal 6a corresponding to the incident wave (see FIG. 1).

[0083] Likewise, second detector circuit 16 rectifies a microwave signal fed from second output part 132, and converts the rectified microwave signal into a direct-current voltage. The thus-converted direct-current voltage is fed to second detection output part 19. Second detection output part 19 transmits, to controller 7, detection signal 6b corresponding to the reflected wave (see FIG. 1).

[0084] Printed circuit board 12 includes four holes (holes 20a, 20b, 20c, and 20d) for attaching printed circuit board 12 to waveguide 10. On board rear surface 12b, copper foils each for serving as a ground are formed at portions around holes 20a, 20b, 20c, and 20d. The portions on which the copper foils are formed have the same voltage as that of board front surface 12a.

[0085] Printed circuit board 12 is fixed to waveguide 10, with screws 201a, 201b, 201c, and 201d (see FIG. 5) being screwed through respective holes 20a, 20b, 20c, and 20d into support part 14.

[0086] As shown in FIG. 6, support part 14 is provided with screw portions 202a, 202b, 202c, and 202d into which screws 201a, 201b, 201c, and 201d are screwed, respectively. Screw portions 202a, 202b, 202c, and 202d are formed in a flange part disposed in support part 14.

[0087] Support part 14 has conductivity, and is disposed so as to surround cross opening 11 in a plan view. Support part 14 functions as a shield that prevents circularly polarized microwaves emitted from cross opening 11 from leaking out of support part 14.

[0088] Support part 14 is provided with groove 141 and groove 142 through which third straight-line portion 13ab and fourth straight-line portion 13bb of microstrip line 13 pass, respectively. With this configuration, both first output part 131 and second output part 132 of microstrip line 13 are allowed to be disposed outside support part 14. Grooves 141 and 142 function as extraction parts for extracting the microwave signals that propagate through microstrip line 13 to the outside of support part 14. Grooves 141 and 142 can be formed by recessing the flange part of support part 14 so as to be away from printed circuit board 12.

[0089] In FIGS. 5 and 6, illustrated are connector 18a and connector 19a that are respectively coupled to first detection output part 18 and second detection output part 19 shown in FIG. 8.

[0090] In the present embodiment, directional coupler 6 has both the function of an incident-wave detection unit and the function of a reflected-wave detection unit. However, the present disclosure is not limited to this. Directional coupler 6 may be configured to have only any one of the function of an incident-wave detection unit and the function of a reflected-wave detection unit. In this case, directional coupler 6 is configured by replacing one of first detector circuit 15 and second detector circuit 16 shown in FIG. 8 with a termination circuit (for example, a chip resistor of 50 Ω).

[0091] Next, the operation and action of directional coupler 6 will be described.

[0092] First, with reference to FIG. 9, a description will be made regarding the principle that a circularly polarized microwave is emitted from cross opening 11. In FIG. 9, magnetic field distribution 10d that appears inside waveguide 10 is illustrated by concentric ellipses depicted with the dotted lines. The directions of magnetic fields in magnetic field distribution 10d are indicated by the arrows. Magnetic field distribution 10d travels through inside waveguide 10 in transmission direction A1 of the microwave with a lapse of time.

[0093] At time $t = t0$ shown in (a) of FIG. 9 magnetic field distribution 10d is formed. At this time, the magnetic field indicated by broken line arrow B1 excites first elongated hole 11e of cross opening 11. At time $t = t0 + t1$ shown in (b) of FIG. 9, the magnetic field indicated by broken line arrow B2 excites second elongated hole 11f of cross opening 11.

[0094] At time $t = t0 + T/2$ (where T is the period of in-tube wavelength λg of the microwave) shown in (c) of FIG. 9, the magnetic field indicated by broken line arrow B3 excites first elongated hole 11e of cross opening 11. At time $t = t0 + T/2 + t1$ shown in (d) of FIG. 9, the magnetic field indicated by broken line arrow B4 excites second elongated hole 11f of cross opening 11. At time $t = t0 + T$, as in the case at $t = t0$, the magnetic field indicated by broken line arrow B1 excites first elongated hole 11e of cross opening 11.

[0095] By repeating these states sequentially, a circularly polarized microwave that rotates counterclockwise (in rotation direction 32 of the microwave) is emitted from cross opening 11 to the outside of waveguide 10.

[0096] Here, assuming that the microwave propagating along arrow 30 shown in FIG. 7 is an incident wave and that the microwave propagating along arrow 31 is a reflected wave, the incident wave then travels in the same direction as transmission direction A1 shown in FIG. 9. This causes, as described above, the circularly polarized microwave that rotates counterclockwise to be emitted from cross opening 11 to the outside of waveguide 10. On the other hand, the reflected wave propagates in the direction opposite to transmission direction A1 shown in FIG. 9. This causes the circularly polarized microwave that rotates clockwise to be emitted from cross opening 11 to the outside of waveguide 10.

[0097] The circularly polarized microwave emitted to the outside of the waveguide 10 is coupled to microstrip line 13 that faces cross opening 11. Microstrip line 13 outputs, to first output prat 131, most of the microwave that is fed by the incident wave propagating along arrow 30 and is emitted from cross opening 11.

[0098] On the other hand, microstrip line 13 outputs, to second output prat 132, most of the microwave that is fed by the reflected wave that propagates along arrow 31 and is emitted from cross opening 11. This allows the incident wave and the reflected wave to be separately detected with higher accuracy. Regarding this, a more detailed description is made with reference to FIG. 10.

[0099] FIG. 10 is a diagram for illustrating the direction and amount of a microwave that propagates through microstrip line 13 and varies with a lapse of time. There is a gap between microstrip line 13 and cross opening 11. In general, the time required for a microwave to arrive at microstrip line 13 is delayed by the time during which the microwave propagates across the gap. However, for convenience, it is assumed that there is no time delay here.

[0100] Here, regions at each of which cross opening 11 intersects microstrip line 13 in a plan view are referred to as coupling regions. First coupling point P1 locates at an approximate center of the coupling region in which first elongated hole 11e intersects microstrip line 13. Second coupling point P2 locates at an approximate center of the coupling region in which second elongated hole 11f intersects microstrip line 13.

[0101] In FIG. 10, the amount (observed as an electric current that flows due to interlinkage of a magnetic field) of the microwave propagating through microstrip line 13 is represented by the thickness of the solid line arrow. That is, when the amount of the microwave propagating through microstrip line 13 is large, it is indicated by the thick arrow; when the amount of the microwave propagating through microstrip line 13 is small, it is indicated by the thin arrow.

[0102] At time t = t0 shown in (a) of FIG. 10, the magnetic field indicated by broken line arrow B1 excites first elongated hole 11e of cross opening 11, and a microwave indicated by thick solid line arrow M1 is generated at first coupling point P1. The microwave propagates through microstrip line 13 toward second coupling point P2.

[0103] At time t = t0 + t1 shown in (b) of FIG. 10, the magnetic field indicated by broken line arrow B2 excites second elongated hole 11f of cross opening 11, and a microwave indicated by thick solid line arrow M2 is generated at second coupling point P2.

[0104] In the case where the effective propagation time of the microwave between first coupling point P1 and second coupling point P2 through microstrip line 13 is set to time t1, the microwave generated at first coupling point P1 at the time shown in (a) of FIG. 10 propagates to second coupling point P2 at the time shown in (b) of FIG. 10. That is, at the time shown in (b) of FIG. 10, both the microwave indicated by solid line arrow M1 and the microwave indicated by solid line arrow M2 occur at second coupling point P2.

[0105] Accordingly, the two microwaves are added and propagate through microstrip line 13 toward second output part 132, and are then fed to second output part 132 after a lapse of a predetermined time. In the present embodiment, in order to set the effective propagation time described above equal to time t1, the sum of a line distance of first transmission line 13a further away from tube axis L1 than virtual straight line L3 and a line distance of second transmission line 13b further away from tube axis L1 than virtual straight line L3, is set equal to 1/4 of effective length λ_{re}. This configuration allows easy designing of microstrip line 13.

[0106] At time t = t0 + T/2 shown in (c) of FIG. 10, the magnetic field indicated by broken line arrow B3 excites first elongated hole 11e of cross opening 11, and a microwave indicated by thin solid line arrow M3 is generated at first coupling point P1. The microwave propagates through microstrip line 13 toward first output part 131, and is fed to first output part 131 after a lapse of a predetermined time.

[0107] The reason why the thickness of solid line arrow M3 is made thinner than that of solid line arrow M1 is as follows: From cross opening 11, a circularly polarized microwave that rotates counterclockwise (in rotation direction 32 of the microwave) is emitted as described above.

[0108] At the time shown in (a) of FIG. 10, the microwave generated at first coupling point P1 indicated by solid line arrow M1 propagates in a direction substantially the same as the rotation direction of the microwave emitted from cross opening 11. For this reason, the energy of the microwave indicated by solid line arrow M1 is not reduced.

[0109] In contrast, at the time shown in (c) of FIG. 10, the microwave generated at first coupling point P1 indicated by solid line arrow M3 propagates in a direction substantially opposite to the rotation direction of the microwave emitted from cross opening 11. For this reason, the energy of the combined microwave is reduced. Accordingly, the amount of the microwave indicated by solid line arrow M3 is smaller than the amount of the microwave indicated by solid line arrow M1.

[0110] At time t = t0 + T/2 + t1 shown in (d) of FIG. 10, the magnetic field indicated by broken line arrow B4 excites second elongated hole 11f of cross opening 11, and a microwave indicated by thin solid line arrow M4 is generated at second coupling point P2. The microwave propagates toward first coupling point P1. The reason why the thickness of solid arrow M4 is made thin is the same as the reason why the thickness of solid arrow M3 is made thin as described above.

[0111] At time t = t0 + T, as in the case at time t = t0 shown in (a) of FIG. 10, the magnetic field indicated by broken line arrow B1 excites first elongated hole 11e of cross opening 11. In this case, although having not been described in the case at the time shown in (a) of FIG. 10, there exists a microwave indicated by thin solid line arrow M4 on microstrip line 13.

[0112] The microwave indicated by thin solid arrow M4 propagates to first coupling point P1 at time t = t0 + T (that is, t = t0). The microwave indicated by thin solid arrow M4 propagates in the direction opposite to the microwave indicated by thick solid arrow M1. Therefore, the microwave indicated by solid arrow M4 is canceled and disappears, and is not fed to first output part 131.

[0113] Strictly speaking, the amount of the microwave propagating from first coupling point P1 at time t = t0 is equal to the amount (M1 - M4) that is obtained by subtracting the amount of the microwave indicated by thin solid arrow M4 from the amount of the microwave indicated by thick solid arrow M1. Accordingly, the amount of the microwave fed to second output part 132 is equal to the amount (M1 + M2 - M4) that is obtained by adding the amount of the microwave indicated by thick solid arrow M2 to the amount of the microwave propagating from second coupling point P2.

[0114] In consideration of this, the amount (M1 + M2 - M4) of the microwave fed to second output part 132 is much larger than the amount (M3) of the microwave fed to first output part 131. Therefore, microstrip line 13 outputs, to second output prat 132, most of the microwave rotating counterclockwise that is fed by the reflected wave propagating along arrow 31 and is emitted from cross opening 11. On the other hand, microstrip line 13 outputs, to first output prat 131, most of the microwave rotating clockwise that is fed by the incident wave propagating along arrow 30 and is emitted from cross opening 11.

[0115] The amount of the microwave emitted from cross opening 11 with respect to the amount of the microwave propagating through waveguide 10 is determined by the shapes and dimensions of waveguide 10 and cross opening 11. For example, in the case where the shapes and dimensions are set to ones described above, the amount of the microwave emitted from cross opening 11 is approximately 1/100000 (approximately -50 dB) times the amount of the microwave propagating through waveguide 10.

[0116] Next, a description will be made regarding the reason why, in the present embodiment, the sum of a line distance of first transmission line 13a further away from tube axis L1 than parallel line L4 and a line distance of second transmission line 13b further away from tube axis L1 than parallel line L4, is set equal to 1/2 of effective length λ_{re}.

[0117] FIG. 11 is a diagram for illustrating the direction and amount of a microwave that propagates through microstrip line 13 and varies with a lapse of time. In (a) to (d) of FIG. 11, the states of (a) to (d) of FIG. 10 after a lapse of time t1/2 are respectively illustrated.

[0118] Although the description is omitted above, magnetic field distribution 10d travels through inside waveguide 10 in transmission direction A1 of the microwave with a lapse of time. Therefore, as shown in (a) to (d) of FIG. 11, the magnetic fields indicated by broken line arrows B12, B23, B34, and B41 excite first elongated hole 11e and second elongated hole 11f. This causes circularly polarized microwaves emitted to the outside of waveguide 10 to be coupled to microstrip line 13.

[0119] Here, in a plan view, a region in which perpendicular line L2 and parallel line L4 intersect microstrip line 13 is referred to as a coupling region. Third coupling point P3 locates at an approximate center of the coupling region in which perpendicular line L2 intersects microstrip line 13. Fourth coupling point P4 locates at an approximate center of the coupling region in which parallel line L4 intersects first transmission line 13a. Fifth coupling point P5 locates at an approximate center of the coupling region in which parallel line L4 intersects second transmission line 13b.

[0120] At time t = t0 + t1/2 shown in (a) of FIG. 11, the magnetic field indicated by broken line arrow B12 excites cross opening 11, and a microwave indicated by thick solid line arrow M11 is generated at third coupling point P3. The microwave propagates through microstrip line 13 toward fifth coupling point P5.

[0121] At time t = t0 + t1 + t1/2 shown in (b) of FIG. 11, the magnetic field indicated by broken line arrow B23 excites cross opening 11. At fifth coupling point P5, a microwave indicated by thick solid line arrow M12a is generated. At fourth coupling point P4, a microwave indicated by thin solid line arrow M12b is generated. The reason why solid line arrow M12b is made thin is the same as the reason why solid line arrow M3 is made thin as described above.

[0122] In the case where the effective propagation time of the microwave between third coupling point P3 and fifth coupling point P5 through microstrip line 13 is set to time t1, the microwave generated at third coupling point P3 at the time shown in (a) of FIG. 11 propagates to fifth coupling point P5 at the time shown in (b) of FIG. 11. That is, at the time shown in (b) of FIG. 11, both the microwave indicated by thick solid line arrow M11 and the microwave indicated by thick solid line arrow M12a occur at fifth coupling point P5.

[0123] Accordingly, the two microwaves are added and propagate through microstrip line 13 toward second output part 132, thereby being fed to second output part 132 after a lapse of a predetermined time. In the present embodiment, in order to set the effective propagation time described above equal to time t1, the line distance of first transmission line 13a further away from tube axis L1 than parallel line L4 is set equal to 1/4 of effective length λ_{re}. The microwave generated at fourth coupling point P4 and indicated by thin solid line arrow M12b, propagates through microstrip line 13 toward first output part 131, and is fed to first output part 131 after a lapse of a predetermined time.

[0124] At time t = t0 + T/2 + t1/2 shown in (c) of FIG. 11, the magnetic field indicated by broken line arrow B34 excites cross opening 11. At third coupling point P3, a microwave indicated by thin solid line arrow M13b is generated. The microwave propagates through microstrip line 13 toward first output part 131. The reason why solid line arrow M13b is made thin is the same as the reason why solid line arrow M3 is made thin as described above.

[0125] At time t = t0 + T/2 + t1 + t1/2 shown in (d) of FIG. 11, the magnetic field indicated by broken line arrow B41 excites cross opening 11. At fifth coupling point P5, a microwave indicated by thin solid line arrow M14b is generated. At fourth coupling point P4, a microwave indicated by thick solid line arrow M14a is generated. The microwave indicated by thin solid line arrow M14b propagates through microstrip line 13 toward third coupling point P3. The reason why solid line arrow M14b is made thin is the same as the reason why solid line arrow M3 is made thin as described above.

[0126] The microwave indicated by thick solid line arrow M14a propagates through microstrip line 13 toward third coupling point P3. In the case where the effective propagation time of the microwave between third coupling point P3 and fourth coupling point P4 through microstrip line 13 is set to time t1, the microwave generated at third coupling point P3 at the time shown in (c) of FIG. 11 propagates to fourth coupling point P4 at the time shown in (d) of FIG. 11.

[0127] That is, at the time shown in (d) of FIG. 11, both the microwave indicated by thin solid line arrow M13b and the microwave indicated by thick solid line arrow M14a occur at fourth coupling point P4. In the present embodiment, in order to set the effective propagation time described above equal to time t1, the line distance of second transmission line 13b further away from tube axis L1 than parallel line L4 is set equal to 1/4 of effective length λ_{re}.

[0128] That is, the sum of a line distance of first transmission line 13a further away from tube axis L1 than parallel line L4 and a line distance of second transmission line 13b further away from tube axis L1 than parallel line L4, is set equal to 1/2 of effective length λ_{re}. The microwave indicated by thin solid arrow M13b propagates in the direction opposite to the microwave indicated by thick solid arrow M14a. Therefore, the microwave indicated by thin solid arrow M13b is canceled and disappears, and is not fed to first output part 131.

[0129] At time t = t0 + T + t1/2, as in the case at time t = t0 + t1/2 shown in (a) of FIG. 11, the magnetic field indicated by broken line arrow B12 excites cross opening 11. In this case, although having not been described in the case at the time shown in (a) of FIG. 11, there exists a microwave indicated by thin solid line arrow M14b on microstrip line 13.

[0130] At time t = t0 + T + t1/2, the microwave indicated by thin solid line arrow M14b propagates to third coupling point P3. The microwave indicated by thin solid arrow M14b propagates in the direction opposite to the microwaves indicated by thick solid arrow M11 and thick solid arrow M14a. Therefore, the microwave indicated by thin solid arrow M14b is canceled and disappears, and is not fed to first output part 131.

[0131] Strictly speaking, at time t = t0 + t1/2, the amount of the microwave propagating from third coupling point P3 is equal to the amount (M11 + M14a - M14b) that is obtained by subtracting the amount of the microwave indicated by thin solid arrow M14b from the amount of the microwaves indicated by thick solid arrows M11 and M14a. Accordingly, the amount of the microwave fed to second output part 132 is equal to the amount (M11+ M12a + M14a - M14b) that is obtained by adding the amount of the microwave indicated by thick solid arrow M12a to the amount of the microwave propagating from third coupling point P3.

[0132] In consideration of this, the amount (M11+ M12a + M14a - M14b) of the microwave fed to second output part 132 is much larger than the amount (M12b) of the microwave fed to first output part 131. Therefore, microstrip line 13 outputs, to second output prat 132, most of the microwave rotating counterclockwise that is fed by the reflected wave propagating along arrow 31 and is emitted from cross opening 11. On the other hand, microstrip line 13 outputs, to first output prat 131, most of the microwave rotating clockwise that is fed by the incident wave propagating along arrow 30 and is emitted from cross opening 11.

[0133] In the present embodiment, the incident-wave detection unit and the reflected-wave detection unit share microstrip line 13 that faces cross opening 11 disposed in the wall surface of waveguide 10. The incident-wave detection unit extracts an incident wave from one end of microstrip line 13. The reflected-wave detection unit extracts a reflected wave from the other end of microstrip line 13. This configuration makes possible the downsizing of the incident-wave detection unit and the reflected-wave detection unit.

[0134] In the present embodiment, directional coupler 6 includes cross opening 11 that is disposed at a position failing to intersect tube axis L1 of waveguide 10 in a plan view, and that emits circularly polarized microwaves. With this configuration, the rotation directions of the circularly polarized microwaves emitted from cross opening 11 are opposite to each other between the incident wave and the reflected wave. By utilizing such a difference in rotation direction between the circularly polarized microwaves, the incident wave and the reflected wave can be separately detected.

[0135] With directional coupler 6 according to the present embodiment, first transmission line 13a includes first straight-line portion 13aa and second transmission line 13b includes second straight-line portion 13ba. With this configuration, the number of bent portions at each of which microstrip line 13 is bent can be reduced as compared with conventional ones. The need for bending microstrip line 13 at a right angle can be eliminated. It is possible to keep the bent portions, at each of which microstrip line 13 is bent, away from a region in the vertical direction of cross opening 11. This allows the incident wave and the reflected wave to be separately detected with higher accuracy.

[0136] With directional coupler 6 according to the present embodiment, first transmission line 13a and second transmission line 13b are coupled to each other at a position, in a plan view, that is outside rectangular region E1 and is away from tube axis L1. This configuration allows the bent portions, at each of which microstrip line 13 is bent, to be separated farther away from the region in the vertical direction of cross opening 11. This allows both first straight-line portion 13aa and second straight-line portion 13ba to be made longer, thereby reducing the impeding of flowing of the electric current in microstrip line 13. As a result, the incident wave and the reflected wave can be separately detected with much higher accuracy.

[0137] With directional coupler 6 according to the present embodiment, first straight-line portion 13aa intersects first elongated hole 11e at a position that is closer to opening-end portion 11ea than opening-center portion 11c, in a plan view. Second straight-line portion 13ba intersects second elongated hole 11f at a position that is closer to opening-end portion 11fa than opening-center portion 11c, in a plan view. In general, the magnetic field generated around opening-end portions 11ea and 11fa is stronger than that generated around opening-center portion 11c. This configuration allows a stronger magnetic field to be coupled to microstrip line 13. Thus, the amount of the electric current flowing in microstrip line 13 is larger. As a result, the incident wave and the reflected wave can be separately detected with much higher accuracy.

[0138] With directional coupler 6 according to the present embodiment, first straight-line portion 13aa intersects first elongated hole 11e at right angles in a plan view. With this configuration, the transmission direction of the microwave indicated by solid line arrow M1 generated at first coupling point P1 is made identical, in direction, to rotation direction 32 of the microwave emitted from cross opening 11. This configuration results in a further increase in the amount of the microwave indicated by solid line arrow M1.

[0139] The transmission direction of the microwave indicated by solid line arrow M3 generated at first coupling point P1 is made opposite, in direction, to rotation direction 32 of the microwave emitted from cross opening 11. This configuration results in a further decrease in the amount of the microwave indicated by solid line arrow M3. As a result, the incident wave and the reflected wave can be separately detected with much higher accuracy.

[0140] With directional coupler 6 according to the present embodiment, second straight-line portion 13ba intersects second elongated hole 11f at right angles in a plan view. With this configuration, the transmission direction of the microwave indicated by solid line arrow M2 generated at second coupling point P2 is made identical, in direction, to rotation direction 32 of the microwave emitted from cross opening 11. This configuration results in a further increase in the amount of the microwave indicated by solid line arrow M2.

[0141] The transmission direction of the microwave indicated by solid line arrow M4 generated at second coupling point P2 is made opposite, in direction, to rotation direction 32 of the microwave emitted from cross opening 11. This configuration results in a further decrease in the amount of the microwave indicated by solid line arrow M4. As a result, the incident wave and the reflected wave can be separately detected with much higher accuracy.

[0142] With directional coupler 6 according to the present embodiment, microstrip line 13 includes: first straight-line portion 13aa, second straight-line portion 13ba, third straight-line portion 13ab, and fourth straight-line portion 13bb. First straight-line portion 13aa and third straight-line portion 13ab are adjacent to and coupled to each other so as to make an obtuse angle. Second straight-line portion 13ba and fourth straight-line portion 13bb are adjacent to and coupled to each other so as to make an obtuse angle.

[0143] With this configuration, the number of the bent portions at each of which microstrip line 13 is bent can be reduced. This allows a reduction in the impeding of flowing of the electric current in the coupling line. As a result, the incident wave and the reflected wave can be separately detected with much higher accuracy.

[0144] With directional coupler 6 according to the present embodiment, the sum of a line distance of first transmission line 13a further away from tube axis L1 than virtual straight line L3 and a line distance of second transmission line 13b further away from tube axis L1 than virtual straight line L3, is set equal to 1/4 of effective length λ_{re}. With this configuration, the incident wave and the reflected wave can be separately detected with much higher accuracy. It is sufficient for the sum of line distances described above to be set equal to approximately 1/4 of effective length λ_{re}; the sum is not necessarily set strictly equal to 1/4 of effective length λ_{re}.

[0145] With directional coupler 6 according to the present embodiment, the sum of a line distance of first transmission line 13a further away from tube axis L1 than parallel line L4 and a line distance of second transmission line 13b further away from tube axis L1 than parallel line L4, is set equal to 1/2 of effective length λ_{re}. With this configuration, the incident wave and the reflected wave can be separately detected with much higher accuracy. It is sufficient for the sum of line distances described above to be set equal to approximately 1/2 of effective length λ_{re}; the sum is not necessarily set strictly equal to 1/2 of effective length λ_{re}.

[0146] As shown in FIG. 8, in the present embodiment, one end of first transmission line 13a and one end of second transmission line 13b are coupled so as to make a right angle. However, the present disclosure is not limited to this. It is sufficient if one end of first transmission line 13a is coupled to one end of second transmission line 13b at a position out of the region of cross opening 11, in a plan view. In the region, there exists a large influence of the magnetic field.

[0147] FIGS. 12 to 17 are plan views respectively showing examples of first to sixth modifications of microstrip line 13. As shown in FIG. 12, both first transmission line 13a and second transmission line 13b may be bent such that the coupling point between one end of first transmission line 13a and one end of second transmission line 13b is separated from opening-center portion 11c.

[0148] As shown in FIG. 13, both first transmission line 13a and second transmission line 13b may be bent such that the coupling point between one end of first transmission line 13a and one end of second transmission line 13b becomes closer to opening-center portion 11c. As shown in FIG. 14, first transmission line 13a and second transmission line 13b may be curved such that the coupling point between one end of first transmission line 13a and one end of second transmission line 13b becomes closer to opening-center portion 11c.

[0149] In the present embodiment, first straight-line portion 13aa and second straight-line portion 13ba respectively correspond to the first intersecting-line portion and the second intersecting-line portion. However, the present disclosure is not limited to this. As shown in FIG. 15, the first intersecting-line portion and the second intersecting-line portion may be respectively circular-arc portion 13ac and circular-arc portion 13bc.

[0150] In the present embodiment, both third straight-line portion 13ab and fourth straight-line portion 13bb are parallel to perpendicular line L2. However, the present disclosure is not limited to this. As shown in FIG. 16, both third straight-line portion 13ab and fourth straight-line portion 13bb may be parallel to parallel line L4.

[0151] In the present embodiment, first transmission line 13a and second transmission line 13b each include a plurality of the straight-line portions. However, the present disclosure is not limited to this. As shown in FIG. 17, each of first transmission line 13a and second transmission line 13b may be configured with one straight-line portion.

[0152] In the present embodiment, cross opening 11 is formed to have line symmetry with respect to perpendicular line L2. Perpendicular line L2 is orthogonal to tube axis L1, and passes through opening-center portion 11c. However, the present disclosure is not limited to this. Cross opening 11 may not be formed to have line symmetry with respect to perpendicular line L2. For example, first elongated hole 11e and second elongated hole 11f may cross each other at a position out of each of their own center portions in their respective longitudinal directions. The length of first elongated hole 11e and the length of second elongated hole 11f may be different from each other.

[0153] In these cases, the opening-cross portion, at which first elongated hole 11e and second elongated hole 11f cross each other, is out of opening-center portion 11c. Cross opening 11 may be formed to have line symmetry with respect to a line that slightly inclines relative to perpendicular line L2, in a plan view.

(New Discovery Regarding In-Tube Standing Wave and Disposition of Reflected-Wave Detection Unit)

[0154] FIG. 19 is a plan view of cross-shaped waveguide 251 for examining the detection accuracy of a reflected wave with respect to the position of the reflected-wave detection unit. As shown in FIG. 19, cross-shaped waveguide 251 includes main waveguide 252 and sub-waveguide 253. Sub-waveguide 253 is orthogonal to main waveguide 252 and coupled to main waveguide 252 via X-shaped openings 254 and 255.

[0155] For qualitative measurements of reflected waves by using a network analyzer, terminal end 256 of main waveguide 252 is closed and short-circuited. Microwave 257 incident from port Q (not shown) of the network analyzer is completely reflected at terminal end 256.

[0156] A part of the reflected wave returns to port Q. The remaining reflected wave is transmitted to sub-waveguide 253 via openings 254 and 255, and then splits into microwave 258 and microwave 259 inside sub-waveguide 253. Microwave 258 is transmitted to port S (not shown) of the network analyzer, while microwave 259 is transmitted to port T (not shown) of the network analyzer.

[0157] Both main waveguide 252 and sub-waveguide 253 have a symmetrical shape. Openings 254 and 255 have the same shape. Openings 254 and 255 are symmetrically disposed with respect to both main waveguide 252 and sub-waveguide 253. Therefore, the amount of microwave 258 and the amount of microwave 259 are equal to each other.

[0158] Main waveguide 252 and sub-waveguide 253 have a waveguide width (usually referred to as "a" dimension) of approximately 100 mm. In-tube wavelength λg of the microwave in main waveguide 252 and sub-waveguide 253 is approximately 154 mm.

[0159] The S parameter actually observed is a typical measurement value by a network analyzer. Specifically, observed with the network analyzer are: ratio S31 of microwave 258 transmitted to port S to microwave 257 incident from port Q, and ratio S41 of microwave 259 transmitted to port T to microwave 257 incident from port Q. Since ratio S31 and ratio S41 are sometimes considerably smaller than 1, they are usually expressed in decibels.

[0160] Using microwaves having a frequency ranging from 2450 to 2500 MHz, ratio S31 and ratio S41 were measured while changing distance Lsf from terminal end 256 of main waveguide 252 to openings 254 and 255. FIG. 20 is a graph showing the result. The horizontal axis represents distance Lsf [mm], and the vertical axis represents ratios S31 and S41 [dB]. The result is now discussed.

[0161] In main waveguide 252, a node of the in-tube standing wave occurs at closed terminal end 256, and another node occurs at every 1/2 (= 77 mm) of in-tube wavelength λg from terminal end 256. Accordingly, in the case of distance Lsf of 154 mm, openings 254 and 255 are disposed at the position of the node.

[0162] Since an antinode occurs at a position out of a node by $\lambda g/4$ (= 38.5 mm), in the case of distance Lsf of 115.5 mm (= $\lambda g \times 3/4$) and 192.5 mm (= $\lambda g \times 5/4$), openings 254 and 255 are disposed at the position of an antinode. The present inventors have found the following two features from the characteristic diagram.

[0163] The first feature relates to sensitivity. In the case of the openings being at the position of the node (distance Lsf = 154 mm), ratios S31 and S41 range from -12 to -21 dB. In the case of the openings being at the position of the antinode (distance Lsf = 115.5 mm, 192.5 mm), ratios S31 and S41 range from -4 to -8 dB. Therefore, ratios S31 and S41 are larger in the case of the openings disposed at the position of the antinode than in the case of the openings disposed at the position of the node.

[0164] That is, the present inventors have found that the disposition of the openings at the antinode allows larger reflected waves to be detected via the openings, leading to an increase in the sensitivity. By averaging the six curves shown in FIG. 20 and comparing the resulting averages, the difference between the ratio (approximately -16 dB) in the case of the openings being at the node and the ratio (approximately -6 dB) in the case of the openings being at the antinode is found to be 10 dB. That is, the disposition of the openings at the position of the antinode provides 10 times higher sensitivity than the disposition of the openings at the position of the node.

[0165] The second feature relates to frequency stability. In the case of the openings being at the position of the node (distance Lsf = 154 mm), ratios S31 and S41 observed in accordance with changes in the frequency, range from -12 to -21 dB. In the case of the openings being at the position of the antinode (distance Lsf = 115.5 mm, 192.5 mm), ratios S31 and S41 observed in accordance with changes in the frequency, range from -4 to -8 dB.

[0166] Accordingly, the variation range (approximately 4 dB) of ratios S31 and S41 in the case of the openings being at the position of the antinode, is smaller than the variation range (approximately 9 dB) of ratios S31 and S41 in the case of the openings being at the position of the node. That is, the present inventors have found that the disposition of the openings at the antinode results in an increase in frequency stability of the reflected wave detected via the openings.

[0167] As described above, detecting the reflected wave at the antinode of the in-tube standing wave makes possible an increase in the sensitivity and the frequency stability. As a result, the state of object 1 being heated can be detected more accurately.

[0168] Next, the case is discussed where the openings are disposed between the position of the antinode (distance Lsf = 115.5 mm, 192.5 mm) and the position of the node (distance Lsf = 154 mm).

[0169] As shown in FIG. 20, ratios S31 and S41 in the case of the openings disposed at the mid-position (distance Lsf = 134.75 mm, 173.25 mm) between the antinode and the node, are not so poor as those in the case of the openings disposed at the position of the node (distance Lsf = 154 mm). Ratios S31 and S41 in this case are rather close to those in the case of the openings disposed at the position of the antinode (distance Lsf = 115.5 mm, 192.5 mm), and so considerably good.

[0170] That is, only in the case where the openings are disposed at the vicinity of the position of the node (distance Lsf = 154 mm), the measurement result is extremely poor. Therefore, unless the openings are disposed at the position of the node, the detection accuracy of the reflected wave can be improved to some extent.

[0171] More safely, disposing the openings at positions closer to the antinode than the mid-position (distance Lsf = 134.75 mm, 173.25 mm) between the antinode and the node, makes possible an increase in the detection accuracy of the reflected wave. These positions are ones that are away from the exact position of the antinode of the in-tube standing wave (or the center position between the two nodes) by not larger than 1/8 of in-tube wavelength λg, in the fore-and-aft direction.

[0172] Specifically, ratios S31 and S41 at these positions are in the range of approximately from -5 to -9 dB. Regarding the sensitivity, the average value of the six curves shown in FIG, 20 is approximately -16 dB in the case of the openings disposed at the position of the node, approximately -6 dB in the case of the openings disposed at the position of the antinode, and approximately -7 dB in the case of the openings disposed at the mid-position between the antinode and the node.

[0173] That is, ratios S31 and S41 in the case of the openings disposed at the mid-position between the antinode and the node, are as much as 9 dB better than those in the case of the openings disposed at the position of the node, and have only a small difference of 1 dB from those in the case of the openings disposed at the position of the antinode.

[0174] Regarding the frequency stability, the variation range of the six curves shown in FIG. 20 is approximately 9 dB in the case of the openings disposed at the position of the node, approximately 2 dB in the case of the openings disposed at the position of the antinode, and approximately 4 dB in the case of the openings disposed at the mid-position between the antinode and the node.

[0175] That is, ratios S31 and S41 in the case of the openings disposed at the mid-position between the antinode and the node, are much better than those in the case of the openings disposed at the position of the node, and are close to, if anything, those in the case of the openings disposed at the position of the antinode. Therefore, disposition of the openings at a position away from the position of the antinode (or the center position between two nodes) by not larger than 1/8 of in-tube wavelength λg, in the fore-and-aft direction, makes possible an increase in the detection accuracy of the reflected wave.

(Aspects and Effects of The Present Disclosure)

[0176] With reference to FIG. 21, descriptions will be made regarding positional relationships between the in-tube standing wave and the disposition of the reflected-wave detection unit, and aspects of the present disclosure. FIG. 21 is an enlarged view of a portion including waveguide 10 and its surroundings in FIG. 1.

[0177] As shown in FIG. 21, the microwave heating device according to an aspect of the present disclosure includes: heating chamber 2 to accommodate a heating target object, magnetron 3 to generate a microwave, waveguide 10, and directional coupler 6.

[0178] Waveguide 10 transmits the microwave generated by magnetron 3 to the heating chamber. Directional coupler 6 is disposed in the vicinity of antinode 302 of in-tube standing wave 301 that occurs inside waveguide 10. Directional coupler 6 includes the reflected-wave detection unit to detect a part of a reflected wave that is a microwave returning from heating chamber 2 to magnetron 3.

[0179] Antinode 302 and node 303 of in-tube standing wave 301 appear alternately every 1/4 of in-tube wavelength λg.

[0180] This configuration allows a reflected wave to be detected in the vicinity of antinode 302 of in-tube standing wave 301. With this configuration, an increase in detection accuracy of the reflected wave can be achieved, thereby resulting in more accurate detection of the state of object 1 being heated.

[0181] In the microwave heating device according to an aspect of the present disclosure,
a center portion of rectangular region E1 circumscribing cross opening 11 is arranged between two nodes 303 of in-tube standing wave 301, thereby causing directional coupler 6 including the reflected-wave detection unit to be disposed in the vicinity of antinode 302 of in-tube standing wave 301.

[0182] This configuration allows the reflected wave to be detected in the vicinity of antinode 302 of in-tube standing wave 301. This achieves an increase in detection accuracy of the reflected wave, thereby resulting in more accurate detection of the state of object 1 being heated.

[0183] Knowing the position of antinode 302 of in-tube standing wave 301 that is invisible is a difficult matter. Use of the position between two adjacent nodes 303 as a guide results in ease of positioning of directional coupler 6.

[0184] In the microwave heating device according to an aspect of the present disclosure,
rectangular region E1 circumscribing cross opening 11 is disposed so as to fail to overlap with two nodes 303 of in-tube standing wave 301, thereby causing directional coupler 6 including the reflected-wave detection unit to be disposed in the vicinity of antinode 302 of in-tube standing wave 301.

[0185] This configuration allows the reflected wave to be detected at a position closer to antinode 302 of in-tube standing wave 301. This achieves an increase in detection accuracy of the reflected wave, thereby resulting in more accurate detection of the state of object 1 being heated.

[0186] In the microwave heating device according to an aspect of the present disclosure,
directional coupler 6 including the reflected-wave detection unit is disposed away from the center position between two nodes 303 of in-tube standing wave 301, in the fore-and-aft direction, by not larger than 1/8 of in-tube wavelength λg, thereby causing the directional coupler to be disposed in the vicinity of antinode 302 of in-tube standing wave 301.

[0187] As described with reference to FIG. 20, the reflected wave can be detected with accuracy to some extent as long as the detection is made at a position away from antinode 302, in the fore-and-aft direction, by not larger than 1/8 of in-tube wavelength λg. This achieves an increase in detection accuracy of the reflected wave, thereby resulting in more accurate detection of the state of object 1 being heated.

[0188] In the microwave heating device according to an aspect of the present disclosure, directional coupler 6 including the reflected-wave detection unit is disposed away from terminal end 304 of waveguide 10 by a distance equal to an odd multiple (3-fold in FIG. 21) of 1/4 of in-tube wavelength λg, thereby causing the directional coupler to be disposed in the vicinity of antinode 302 of in-tube standing wave 301.

[0189] This configuration allows the reflected wave to be detected in the vicinity of antinode 302 of in-tube standing wave 301. This achieves an increase in detection accuracy of the reflected wave, thereby resulting in more accurate detection of the state of object 1 being heated.

[0190] The microwave heating device according to an aspect of the present disclosure further includes standing-wave stabilizing part 5 for stabilizing the position of in-tube standing wave 301 occurring inside waveguide 10. Directional coupler 6 including the reflected-wave detection unit is disposed away from standing-wave stabilizing part 5 by a distance equal to an odd multiple (1-fold in FIG. 21) of 1/4 of in-tube wavelength λg, thereby causing the directional coupler to be disposed in the vicinity of antinode 302 of in-tube standing wave 301.

[0191] This configuration allows the reflected wave to be detected in the vicinity of antinode 302 of in-tube standing wave 301. This achieves an increase in detection accuracy of the reflected wave, thereby resulting in more accurate detection of the state of object 1 being heated.

[0192] In the microwave heating device according to an aspect of the present disclosure, standing-wave stabilizing part 5 is configured with a projection part that protrudes into the inside of waveguide 10.

[0193] With the configuration, node 303 of in-tube standing wave 301 occurs at the position of the projection part. Directional coupler 6 including the reflected-wave detection unit is disposed away from the projection part by a distance equal to an odd multiple of 1/4 of in-tube wavelength λg, thereby allowing the directional coupler to detect the reflected wave in the vicinity of antinode 302 of in-tube standing wave 301. This achieves an increase in detection accuracy of the reflected wave, thereby resulting in more accurate detection of the state of object 1 being heated.

[0194] In the microwave heating device according to an aspect of the present disclosure, waveguide 10 includes bent portion 10b bent in an L-shape (see FIG. 3), and the standing-wave stabilizing part may be configured with bent portion 10b.

[0195] With the configuration, node 303 of in-tube standing wave 301 occurs at the position of bent portion 10b. Directional coupler 6 including the reflected-wave detection unit is disposed away from bent portion 10b by a distance equal to an odd multiple of 1/4 of in-tube wavelength λg, thereby allowing the directional coupler to detect the reflected wave at the position of antinode 302 of in-tube standing wave 301. This achieves an increase in detection accuracy of the reflected wave, thereby resulting in more accurate detection of the state of object 1 being heated.

[0196] In the microwave heating device according to an aspect of the present disclosure, directional coupler 6 including the reflected-wave detection unit is disposed away from coupling position 305 of magnetron 3 and waveguide 10 by a distance equal to an integral multiple (2-fold in FIG. 21) of 1/2 of in-tube wavelength λg, thereby causing the directional coupler to be disposed in the vicinity of antinode 302 of in-tube standing wave 301.

[0197] With the configuration, antinode 302 of in-tube standing wave 301 occurs at coupling position 305. Directional coupler 6 including the reflected-wave detection unit is disposed away from coupling position 305 by a distance equal to an integral multiple of 1/2 of in-tube wavelength λg, thereby allowing the directional coupler to detect the reflected wave in the vicinity of antinode 302 of in-tube standing wave 301. This achieves an increase in detection accuracy of the reflected wave, thereby resulting in more accurate detection of the state of object 1 being heated.

[0198] The microwave heating device according to an aspect of the present disclosure includes antenna 4 for emitting, into heating chamber 2, the microwave transmitted by waveguide 10. Directional coupler 6 including the reflected-wave detection unit is disposed away from coupling position 306 of antenna 4 and waveguide 10 by a distance equal to an integral multiple (1-fold in FIG. 21) of 1/2 of in-tube wavelength λg, thereby causing the directional coupler to be disposed in the vicinity of antinode 302 of in-tube standing wave 301.

[0199] With the configuration, antinode 302 of in-tube standing wave 301 occurs at coupling position 306. Directional coupler 6 including the reflected-wave detection unit is disposed away from coupling position 306 by a distance equal to an integral multiple of 1/2 of in-tube wavelength λg, thereby allowing the directional coupler to detect the reflected wave in the vicinity of antinode 302 of in-tube standing wave 301. This achieves an increase in detection accuracy of the reflected wave, thereby resulting in more accurate detection of the state of object 1 being heated.

[0200] In the microwave heating device according to an aspect of the present disclosure, directional coupler 6 including the reflected-wave detection unit includes: cross opening 11 disposed in waveguide 10, and a coupling line (see FIG. 8) facing cross opening 11. Cross opening 11 is disposed in the vicinity of antinode 302 of in-tube standing wave 301.

[0201] This configuration allows the reflected wave to be detected at the position of antinode 302 of in-tube standing wave 301. This achieves an increase in detection accuracy of the reflected wave, thereby resulting in more accurate detection of the state of object 1 being heated.

[0202] In the microwave heating device according to an aspect of the present disclosure, cross opening 11 includes first elongated hole 11e and second elongated hole 11f which cross each other (see FIGS. 7 and 8), and is disposed at a position that fails to intersect the tube axis of waveguide 10 in a plan view. The opening-cross portion (see FIGS. 7 and 8) at which first elongated hole 11e and second elongated hole 11f cross each other is disposed in the vicinity of antinode 302 of in-tube standing wave 301.

[0203] With this configuration, the microwave transmitted by waveguide 10 is emitted into heating chamber 2 as a circularly polarized microwave in which the direction of the electric field rotates about the opening-cross portion. As for the circularly polarized microwave, since the incident wave and the reflected wave exhibit rotation directions opposite to each other, the incident wave and the reflected wave can be easily separated from each other. On top of this, with the configuration, the reflected wave is detected in the vicinity of antinode 302 of the in-tube standing wave. This achieves an increase in detection accuracy of the reflected wave, thereby resulting in more accurate detection of the state of object 1 being heated.

INDUSTRIAL APPLICABILITY

[0204] The present disclosure is applicable to microwave heating devices for consumer or industrial use.

REFERENCE MARKS IN THE DRAWINGS

[0205]

1	heating target object
2	heating chamber
2a	loading stand
3	magnetron
4	antenna
5	standing-wave stabilizing part
6, 60	directional coupler
7	controller
7a	signal
8	drive power supply
9	motor

10	waveguide
10a	wide plane
10b	bent portion
10d	magnetic field distribution
11	cross opening
11c	opening-center portion
11d	width
11e	first elongated hole
11ea, 11fa	opening-end portion
11f	second elongated hole
11w	length
12	printed circuit board
12a	board front surface
12b	board rear surface
13	microstrip line
13a	first transmission line
13aa	first straight-line portion
13ab	third straight-line portion
13ac, 13bc	circular-arc portion
13b	second transmission line
13ba	second straight-line portion
13bb	fourth straight-line portion
14	support part
15	first detector circuit
16	second detector circuit
18	first detection output part
18a, 19a	connector
19	second detection output part
50	microwave heating device
131	first output part
132	second output part
141, 142	groove
251	cross-shaped waveguide
252	main waveguide
253	sub-waveguide
254, 255	opening
256, 304	terminal end
257, 258, 259	microwave
301	in-tube standing wave
302	antinode
303	node
305	coupling position
E1	rectangular region
L1	tube axis
L2	perpendicular line
L3	virtual straight line
L4	parallel line
P1	first coupling point
P2	second coupling point
P3	third coupling point
P4	fourth coupling point
P5	fifth coupling point

Claims

1. A microwave heating device, comprising:

a heating chamber configured to accommodate a heating target object;
a microwave generating unit configured to generate a microwave;
a waveguide configured to transmit, to the heating chamber, the microwave generated by the microwave generating unit; and
a reflected-wave detection unit disposed in a vicinity of an antinode of an in-tube standing wave occurring inside the waveguide, the reflected-wave detection unit being configured to detect a part of a reflected wave of the microwave, the reflected wave returning from the heating chamber to the microwave generating unit.

2. The microwave heating device according to claim 1, wherein the reflected-wave detection unit is disposed between two nodes of the in-tube standing wave such that the reflected-wave detection unit is disposed in the vicinity of the antinode of the in-tube standing wave.

3. The microwave heating device according to claim 2, wherein the reflected-wave detection unit is disposed so as to fail to overlap with the two nodes of the in-tube standing wave such that the reflected-wave detection unit is disposed in the vicinity of the antinode of the in-tube standing wave.

4. The microwave heating device according to claim 3, wherein the reflected-wave detection unit is disposed away from a center position between the two nodes of the in-tube standing wave, in a fore-and-aft direction, by not larger than 1/8 of an in-tube wavelength of the in-tube standing wave such that the reflected-wave detection unit is disposed in the vicinity of the antinode of the in-tube standing wave.

5. The microwave heating device according to claim 1,
wherein the waveguide includes a terminal end; and
the reflected-wave detection unit is disposed away from the terminal end by a distance equal to an odd multiple of 1/4 of an in-tube wavelength of the in-tube standing wave such that the reflected-wave detection unit is disposed in the vicinity of the antinode of the in-tube standing wave.

6. The microwave heating device according to claim 1, further comprising:

a standing-wave stabilizing part configured to stabilize a position of the in-tube standing wave,
wherein the reflected-wave detection unit is disposed away from
the standing-wave stabilizing part by a distance equal to an odd multiple of 1/4 of an in-tube wavelength of the in-tube standing wave such that the reflected-wave detection unit is disposed in the vicinity of the antinode of the in-tube standing wave.

7. The microwave heating device according to claim 6, wherein the standing-wave stabilizing part includes a projection part protruding into an inside of the waveguide.

8. The microwave heating device according to claim 6,
wherein the waveguide includes a bent portion bent in an L-shape; and
the standing-wave stabilizing part includes the bent portion.

9. The microwave heating device according to claim 1,
wherein the microwave generating unit and the waveguide are coupled to each other at a coupling position; and
the reflected-wave detection unit is disposed away from the coupling position by a distance equal to an integral multiple of 1/2 of an in-tube wavelength of the in-tube standing wave such that the reflected-wave detection unit is disposed in the vicinity of the antinode of the in-tube standing wave.

10. The microwave heating device according to claim 1, further comprising:

a microwave emitting part configured to emit, into the heating chamber, the microwave transmitted by the waveguide, the microwave emitting part and the waveguide being coupled to each other at a coupling position,
wherein the reflected-wave detection unit is disposed away from the coupling position by a distance equal to an integral multiple of 1/2 of an in-tube wavelength of the in-tube standing wave such that the reflected-wave detection unit is disposed in the vicinity of the antinode of the in-tube standing wave.

11. The microwave heating device according to claim 1,
wherein the reflected-wave detection unit includes:

an opening disposed in the waveguide; and
a coupling line facing the opening; and

the opening is disposed in the vicinity of the antinode of the in-tube standing wave.

12. The microwave heating device according to claim 11,
wherein the waveguide has a tube axis;
the opening is disposed at a position failing to intersect the tube axis in a plan view, the opening including:

a first elongated hole; and
a second elongated hole, the first elongated hole and the second elongated hole crossing each other at an opening-cross portion; and

the opening-cross portion is disposed in the vicinity of the antinode of the in-tube standing wave.

Amended claims under Art. 19.1 PCT

1. (Amended) A microwave heating device, comprising:

a heating chamber configured to accommodate a heating target object;
a microwave generating unit configured to generate a microwave;
a waveguide configured to transmit, to the heating chamber, the microwave generated by the microwave generating unit;
a reflected-wave detection unit disposed in a vicinity of an antinode of an in-tube standing wave occurring inside the waveguide, the reflected-wave detection unit being configured to detect a part of a reflected wave of the microwave, the reflected wave returning from the heating chamber to the microwave generating unit; and
a standing-wave stabilizing part configured to stabilize a position of the in-tube standing wave,
wherein the reflected-wave detection unit is disposed away from the standing-wave stabilizing part by a distance equal to an odd multiple of 1/4 of an in-tube wavelength of the in-tube standing wave.

2. The microwave heating device according to claim 1, wherein the reflected-wave detection unit is disposed between two nodes of the in-tube standing wave such that the reflected-wave detection unit is disposed in the vicinity of the antinode of the in-tube standing wave.

3. The microwave heating device according to claim 2, wherein the reflected-wave detection unit is disposed so as to fail to overlap with the two nodes of the in-tube standing wave such that the reflected-wave detection unit is disposed in the vicinity of the antinode of the in-tube standing wave.

4. The microwave heating device according to claim 3, wherein the reflected-wave detection unit is disposed away from a center position between the two nodes of the in-tube standing wave, in a fore-and-aft direction, by not larger than 1/8 of the in-tube wavelength of the in-tube standing wave such that the reflected-wave detection unit is disposed in the vicinity of the antinode of the in-tube standing wave.

5. The microwave heating device according to claim 1,
wherein the waveguide includes a terminal end; and
the reflected-wave detection unit is disposed away from the terminal end by a distance equal to an odd multiple of 1/4 of the in-tube wavelength of the in-tube standing wave such that the reflected-wave detection unit is disposed in the vicinity of the antinode of the in-tube standing wave.

6. (Cancelled)

7. (Amended) The microwave heating device according to claim 1, wherein the standing-wave stabilizing part includes a projection part protruding into an inside of the waveguide.

8. (Amended) The microwave heating device according to claim 1,
wherein the waveguide includes a bent portion bent in an L-shape; and
the standing-wave stabilizing part includes the bent portion.

9. The microwave heating device according to claim 1,
wherein the microwave generating unit and the waveguide are coupled to each other at a coupling position; and the reflected-wave detection unit is disposed away from the coupling position by a distance equal to an integral multiple of 1/2 of the in-tube wavelength of the in-tube standing wave such that the reflected-wave detection unit is disposed in the vicinity of the antinode of the in-tube standing wave.

10. The microwave heating device according to claim 1, further comprising:

a microwave emitting part configured to emit, into the heating chamber, the microwave transmitted by the waveguide, the microwave emitting part and the waveguide being coupled to each other at a coupling position, wherein the reflected-wave detection unit is disposed away from the coupling position by a distance equal to an integral multiple of 1/2 of the in-tube wavelength of the in-tube standing wave such that the reflected-wave detection unit is disposed in the vicinity of the antinode of the in-tube standing wave.

11. The microwave heating device according to claim 1,
wherein the reflected-wave detection unit includes:

an opening disposed in the waveguide; and
a coupling line facing the opening; and

the opening is disposed in the vicinity of the antinode of the in-tube standing wave.

12. The microwave heating device according to claim 11,
wherein the waveguide has a tube axis;
the opening is disposed at a position failing to intersect the tube axis in a plan view, the opening including:

a first elongated hole; and
a second elongated hole, the first elongated hole and the second elongated hole crossing each other at an opening-cross portion; and

the opening-cross portion is disposed in the vicinity of the antinode of the in-tube standing wave.

FIG. 1

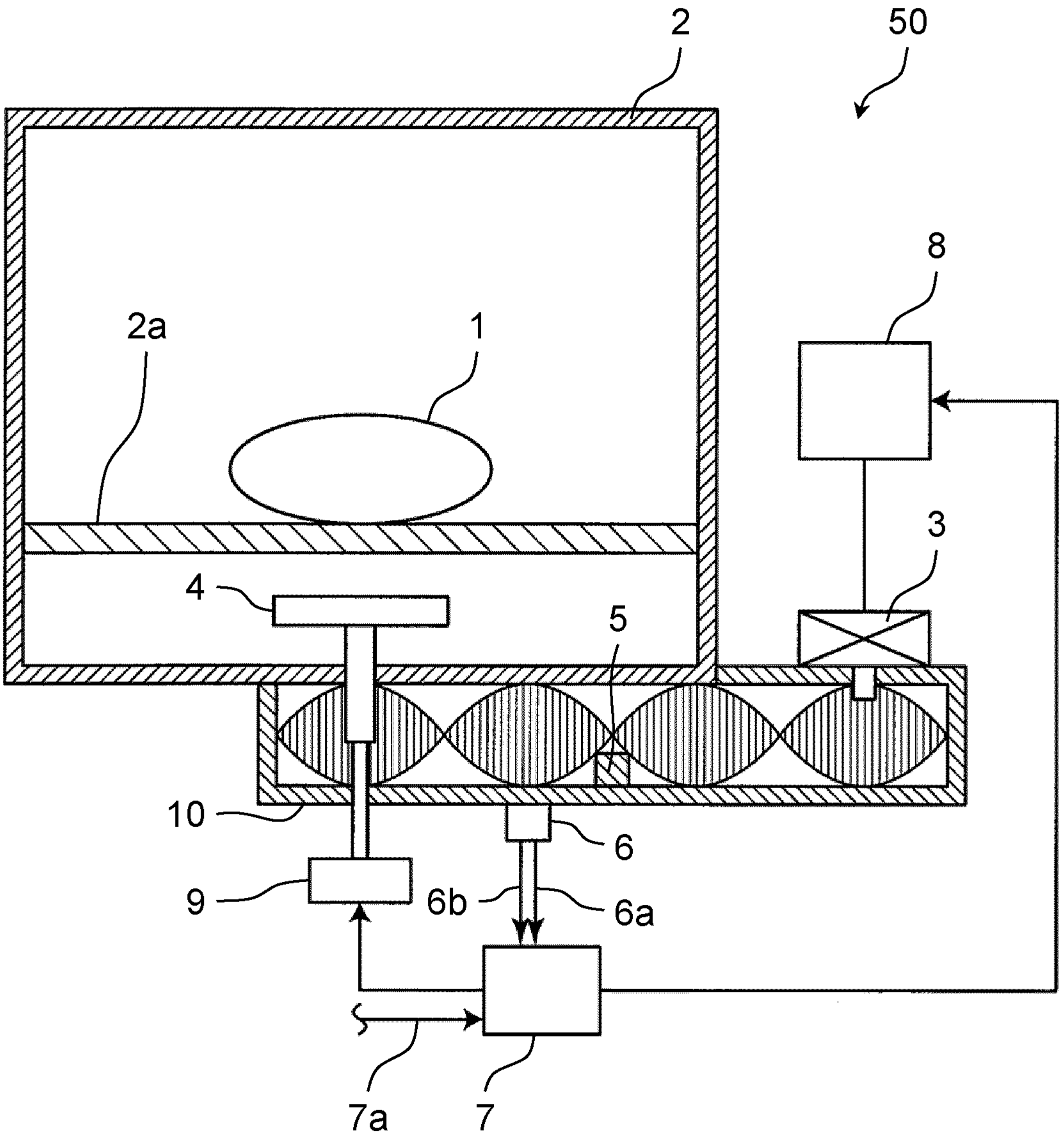


FIG. 2

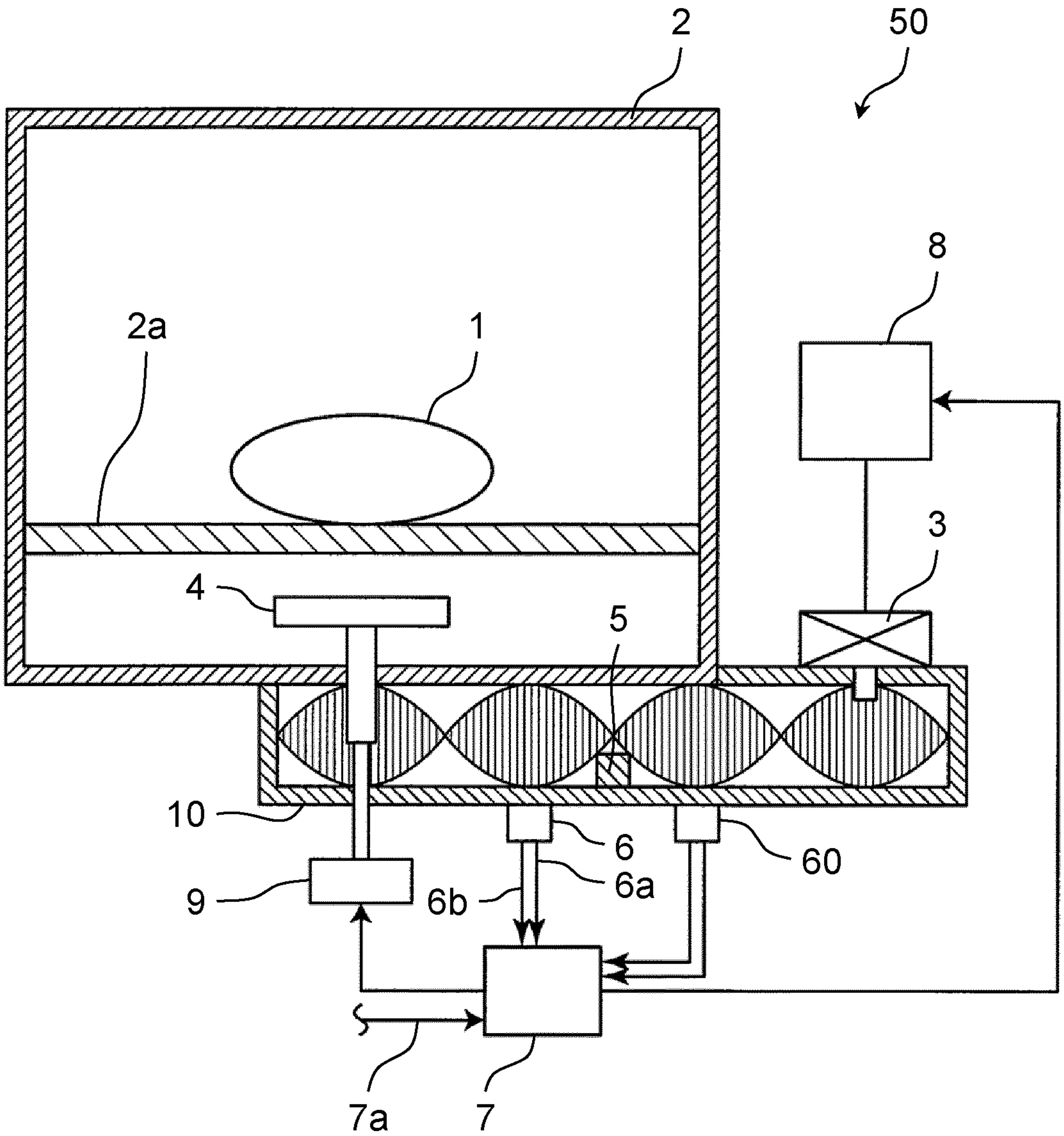


FIG. 3

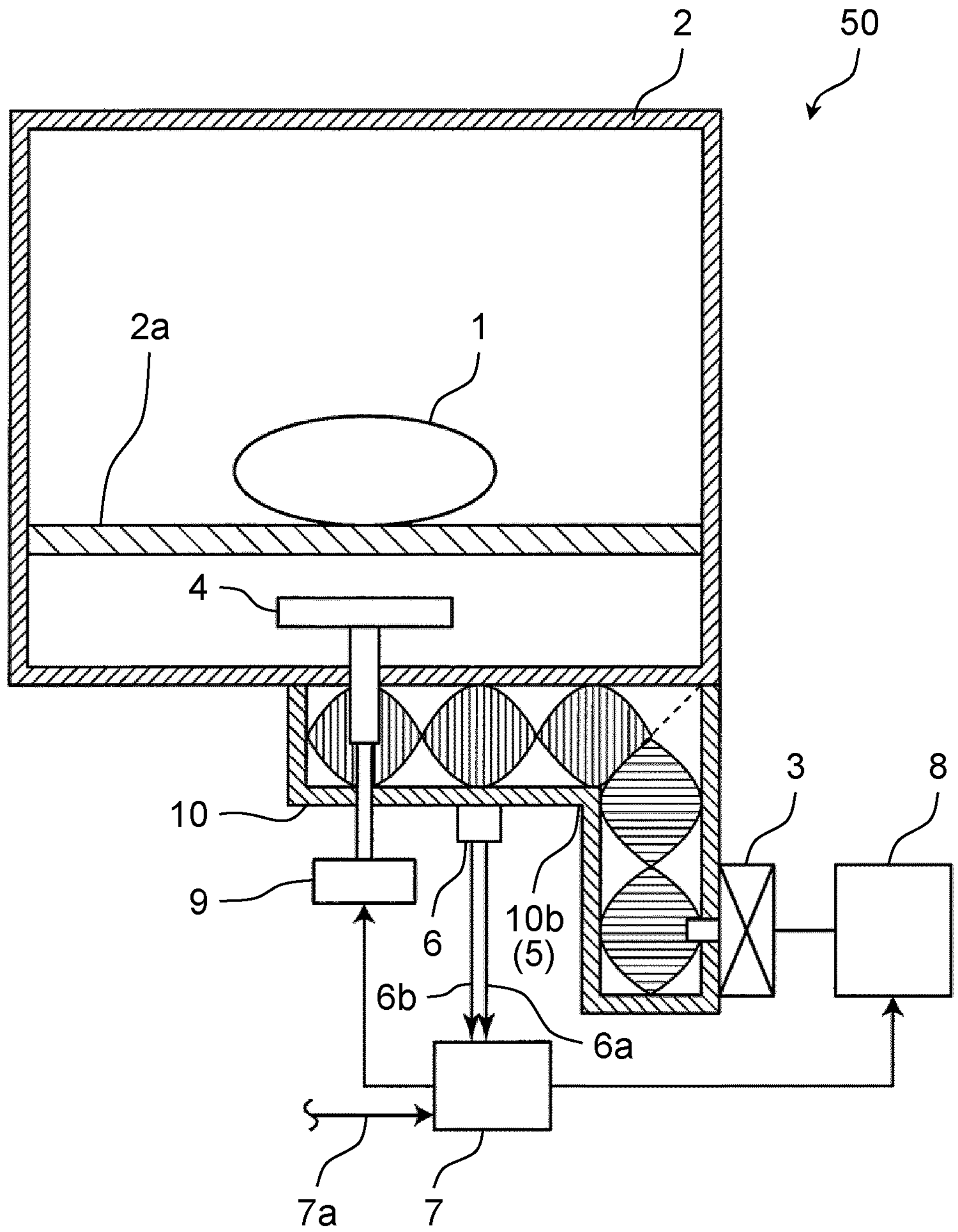


FIG. 4

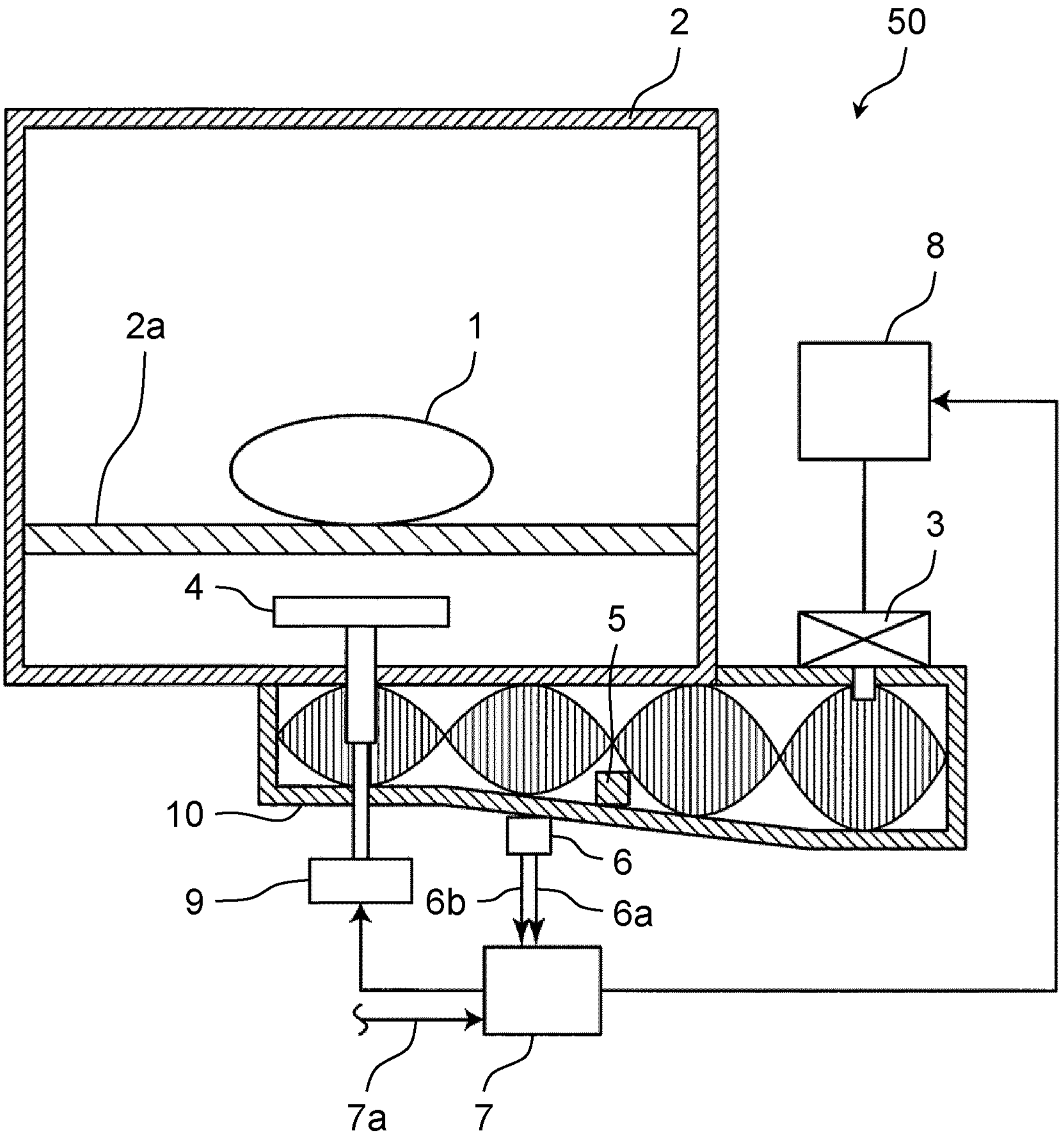


FIG. 5

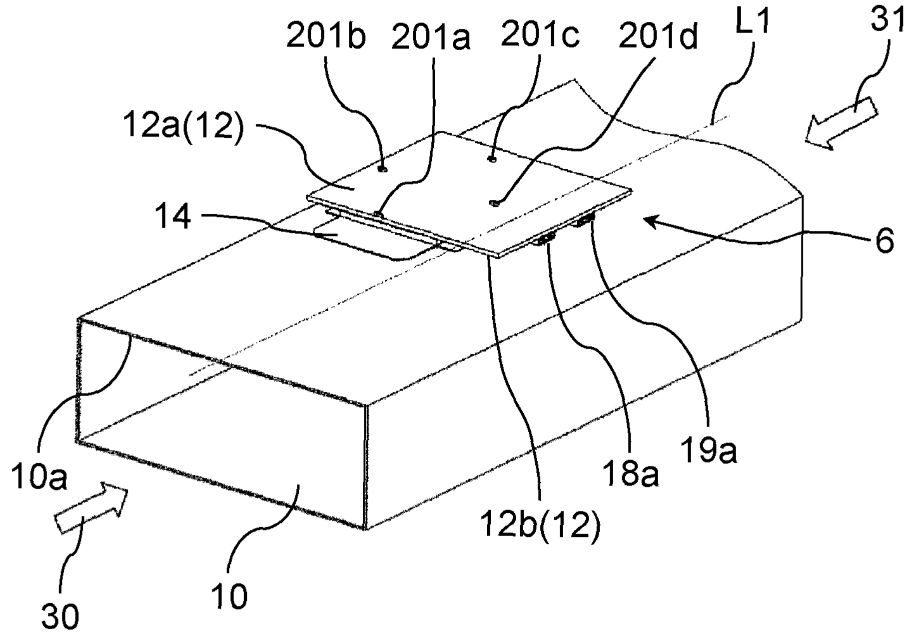

201b
201a
201c
201d
L1
31
12a(12)
14
6
10a
18a
19a
12b(12)
30
10

FIG. 6

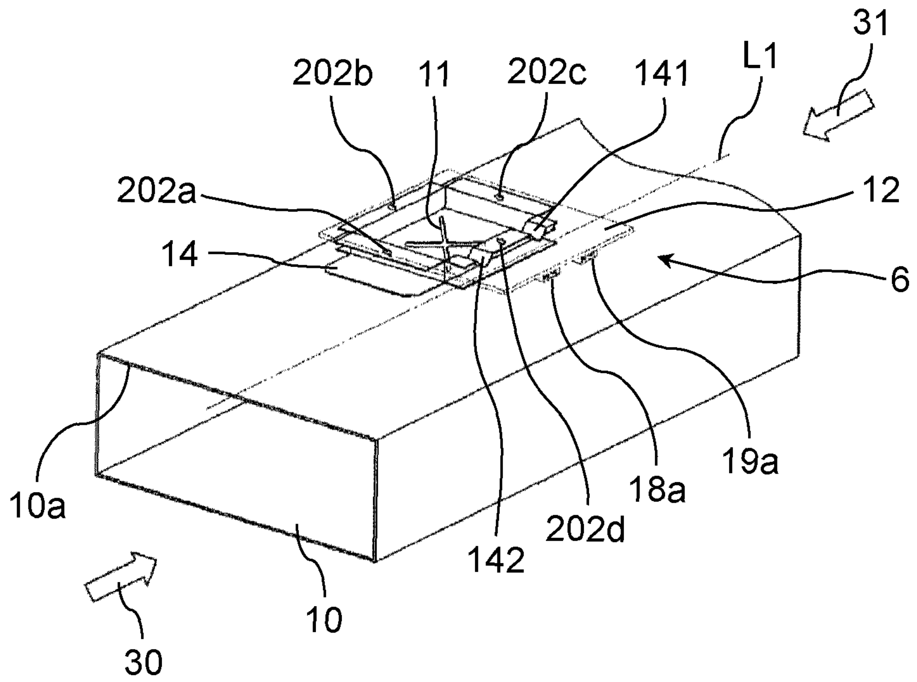

202b
11
202c
141
L1
31
202a
12
14
6
10a
142
202d
18a
19a
10
30

FIG. 7

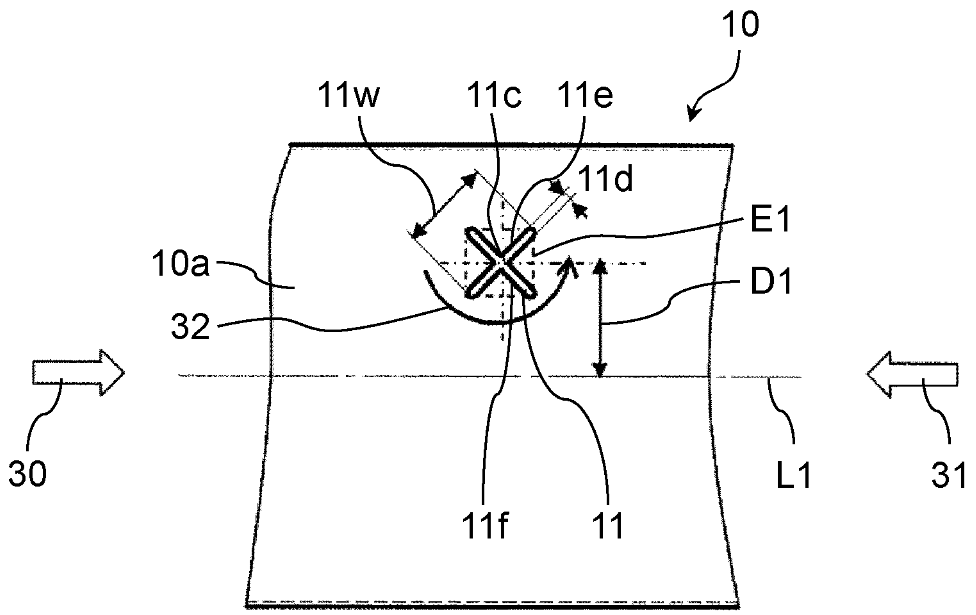


FIG. 8

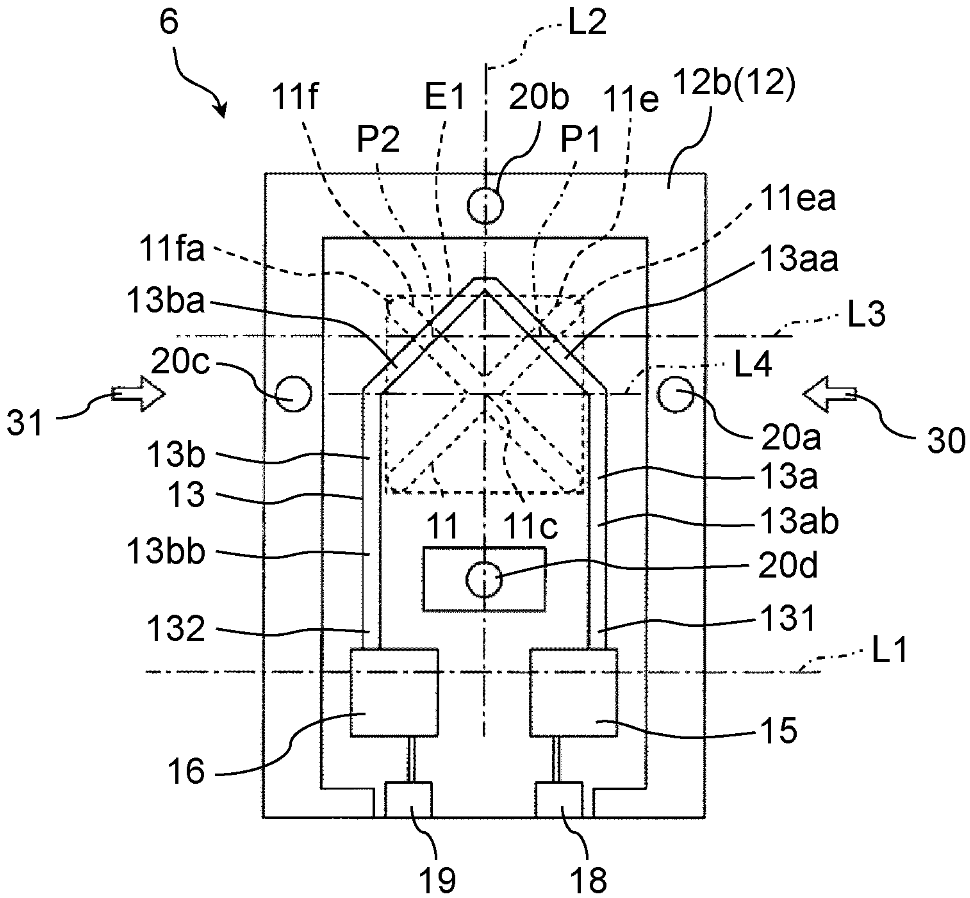

6
L2
11f
E1
20b
11e
12b(12)
P2
P1
11ea
11fa
13aa
13ba
L3
20c
L4
31
20a
30
13b
13a
13
11
11c
13ab
13bb
20d
132
131
L1
16
15
19
18

FIG. 9

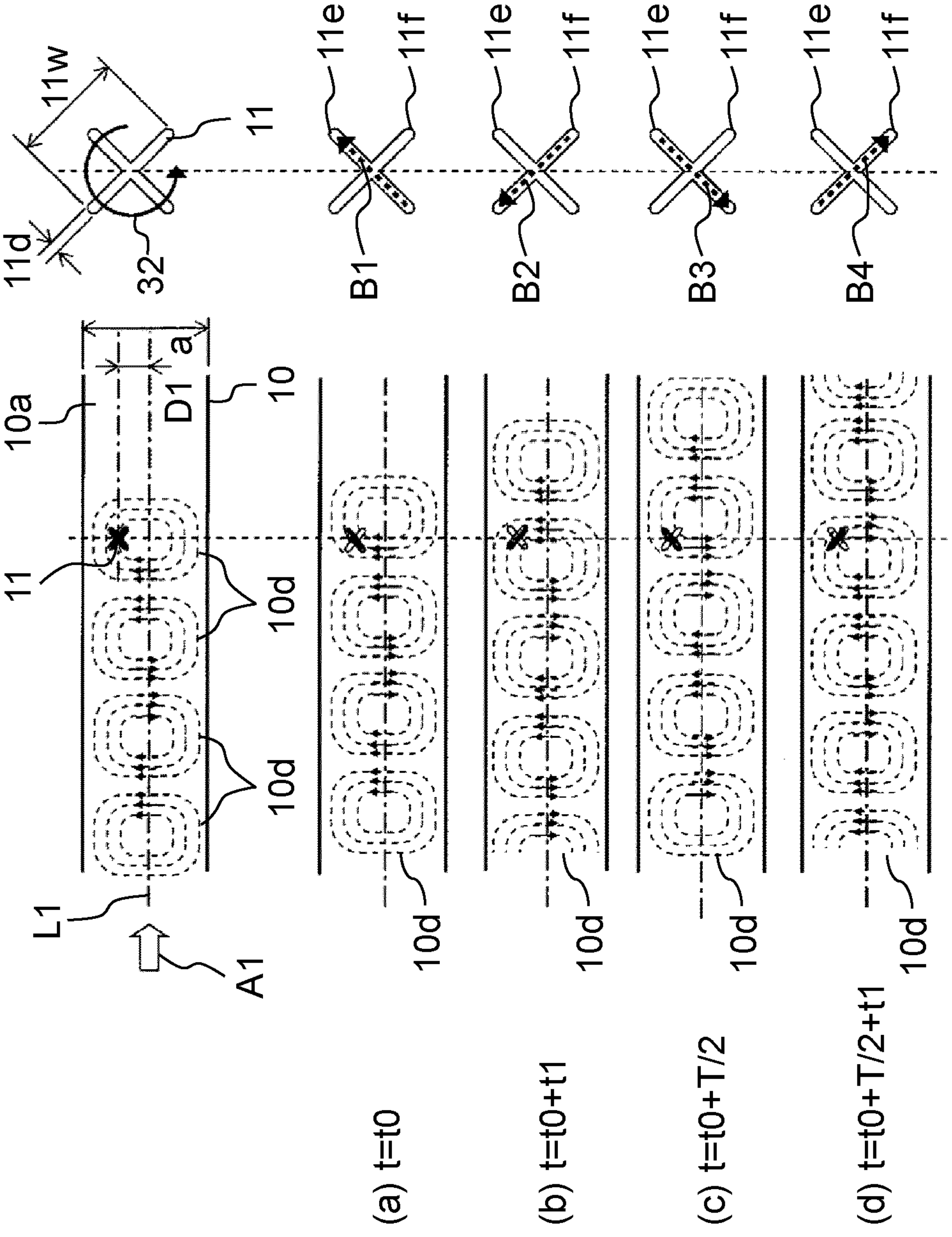
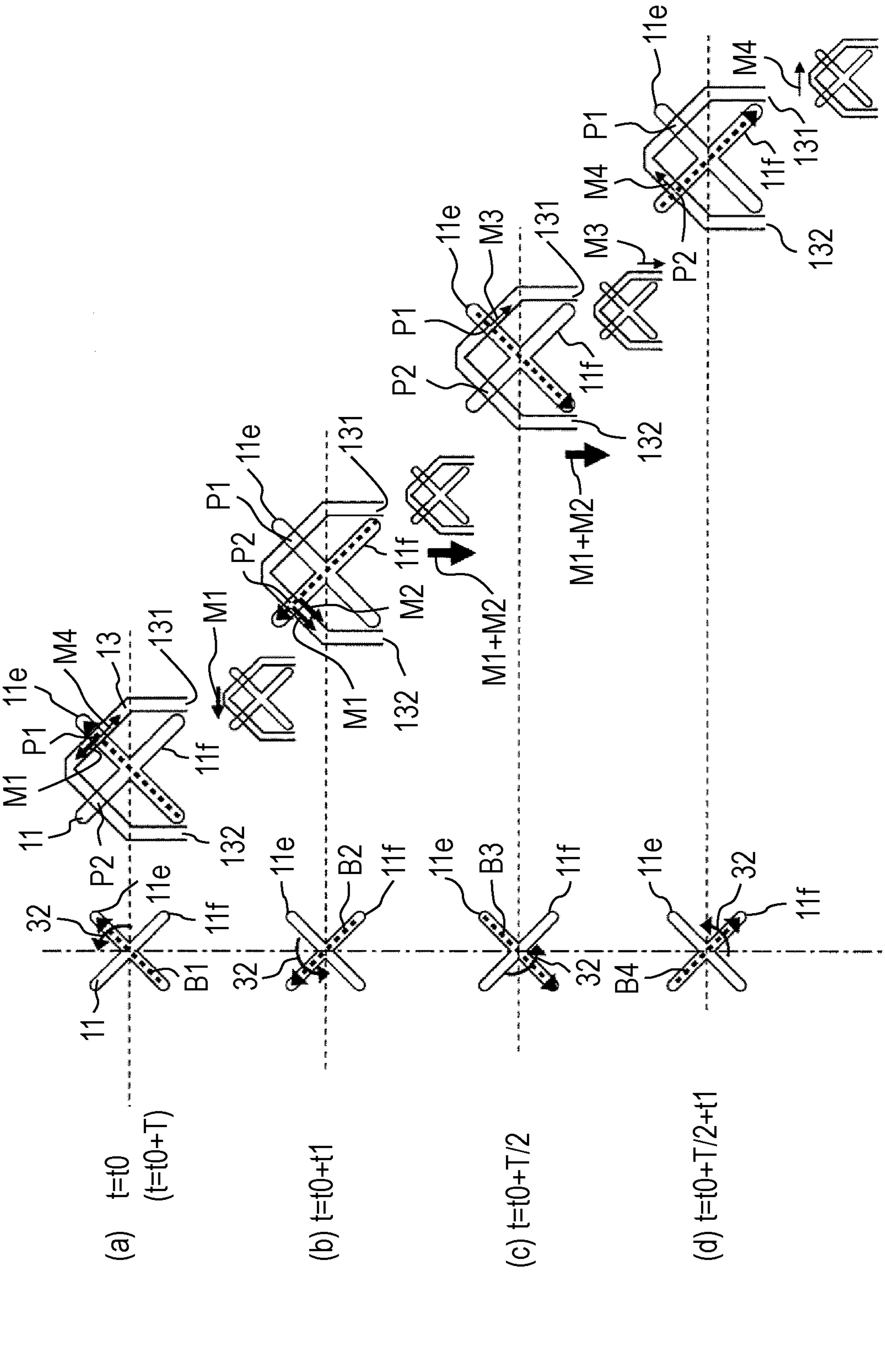

11w
11
11d
32
11e
11f
B1
B2
B3
B4
10a
10
D1
a
11
10d
L1
A1
(a) t=t0
(b) t=t0+t1
(c) t=t0+T/2
(d) t=t0+T/2+t1

FIG. 10



(a) t=t0 (t=t0+T)
(b) t=t0+t1
(c) t=t0+T/2
(d) t=t0+T/2+t1
11
11e
11f
13
131
132
32
P1
P2
M1
M2
M3
M4
M1+M2
B1
B2
B3
B4

FIG. 11

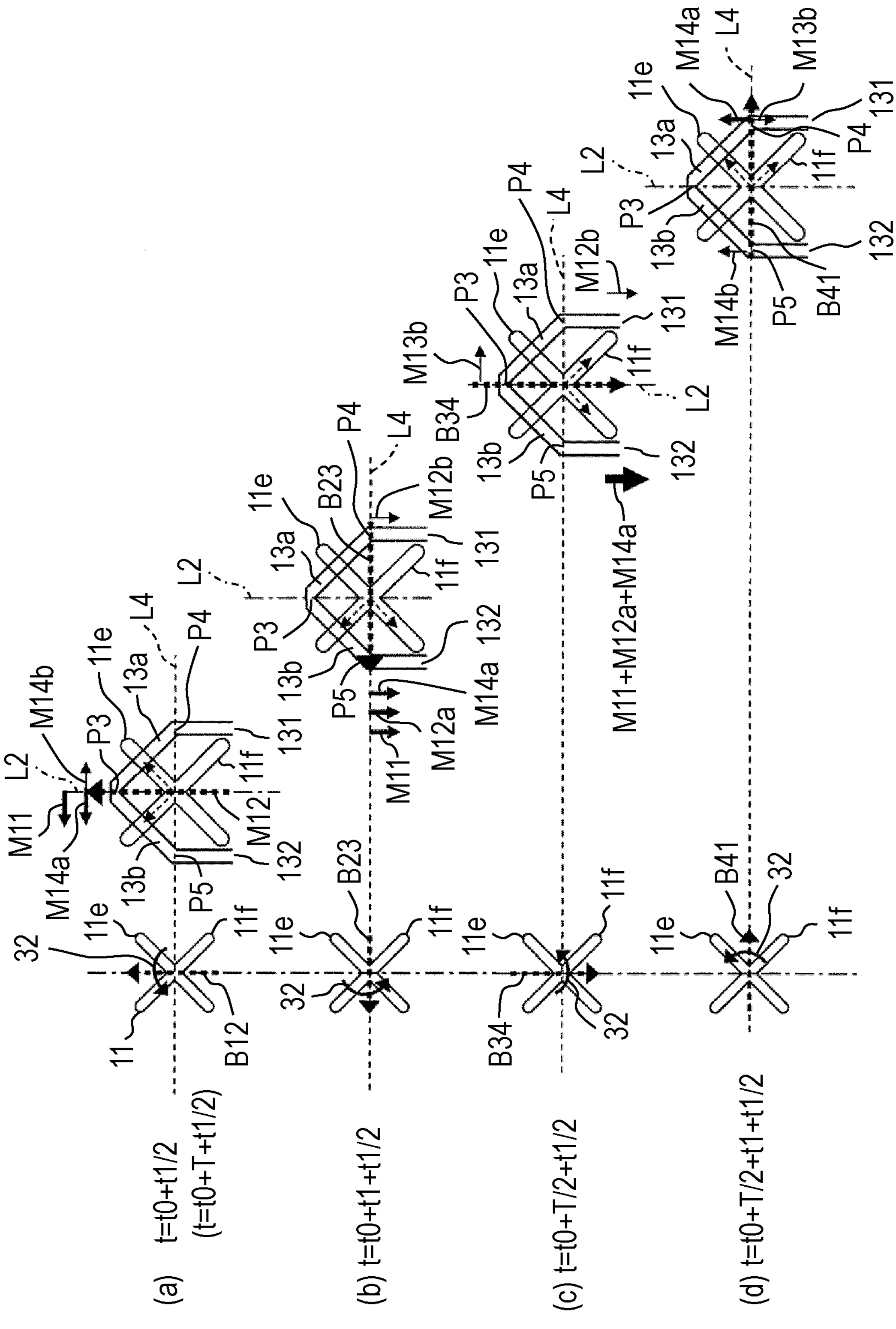

(a) t=t0+t1/2
(t=t0+T+t1/2)
(b) t=t0+t1+t1/2
(c) t=t0+T/2+t1/2
(d) t=t0+T/2+t1+t1/2
M11+M12a+M14a
11
11e
11f
32
B12
B23
B34
B41
M11
M12
M12a
M12b
M13b
M14a
M14b
L2
L4
P3
P4
P5
13a
13b
131
132

FIG. 12

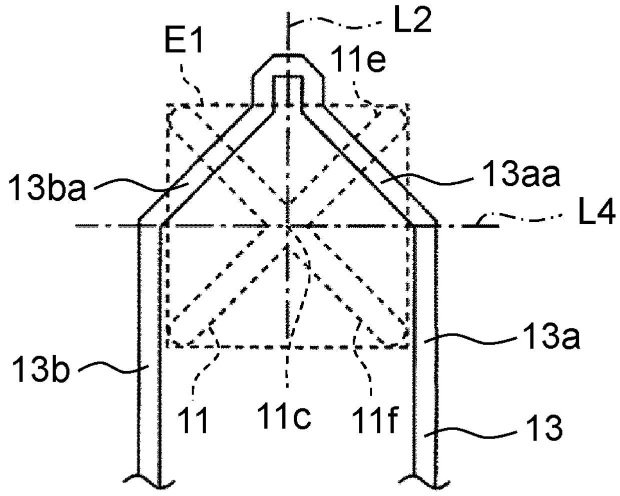


FIG. 13

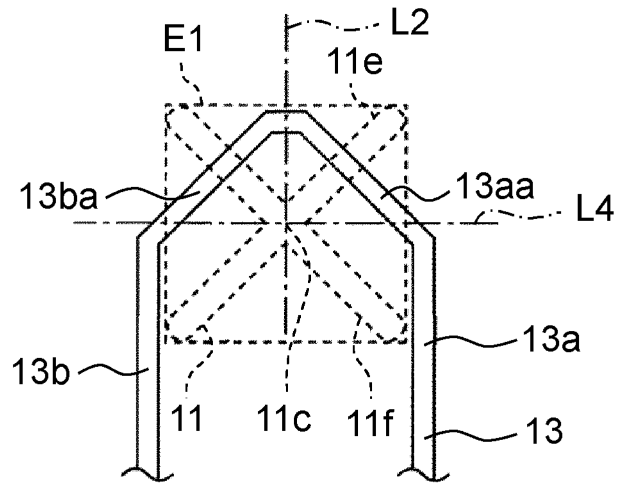


FIG. 14

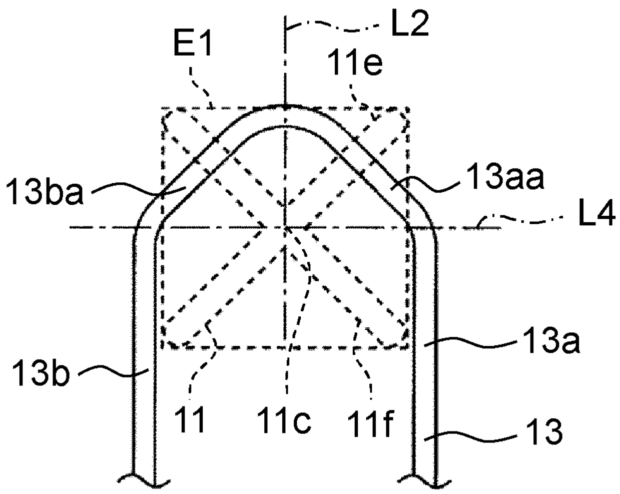


FIG. 15

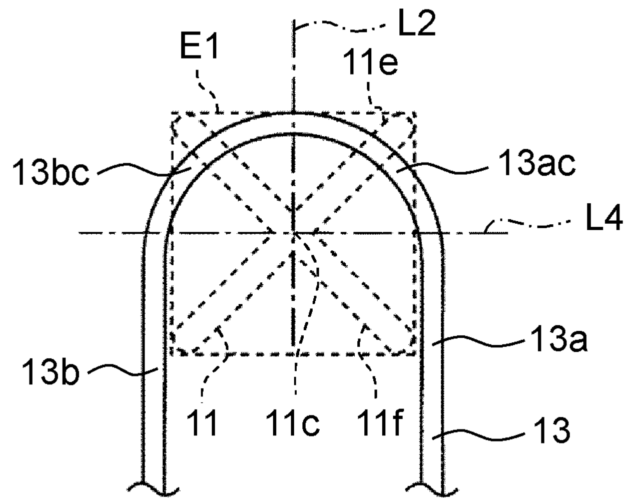


FIG. 16

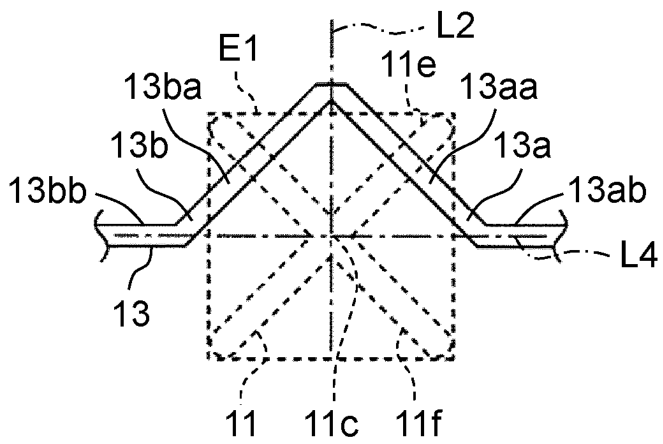


FIG. 17

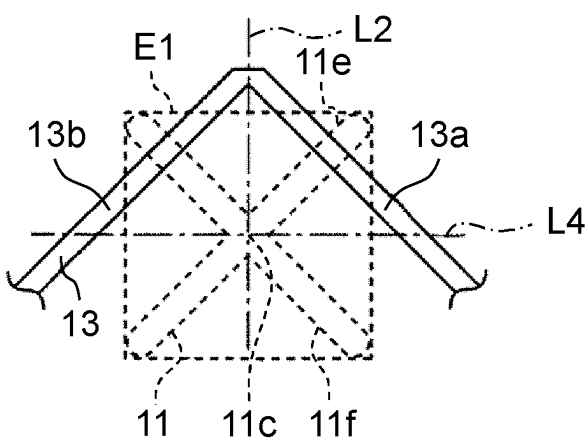


FIG. 18

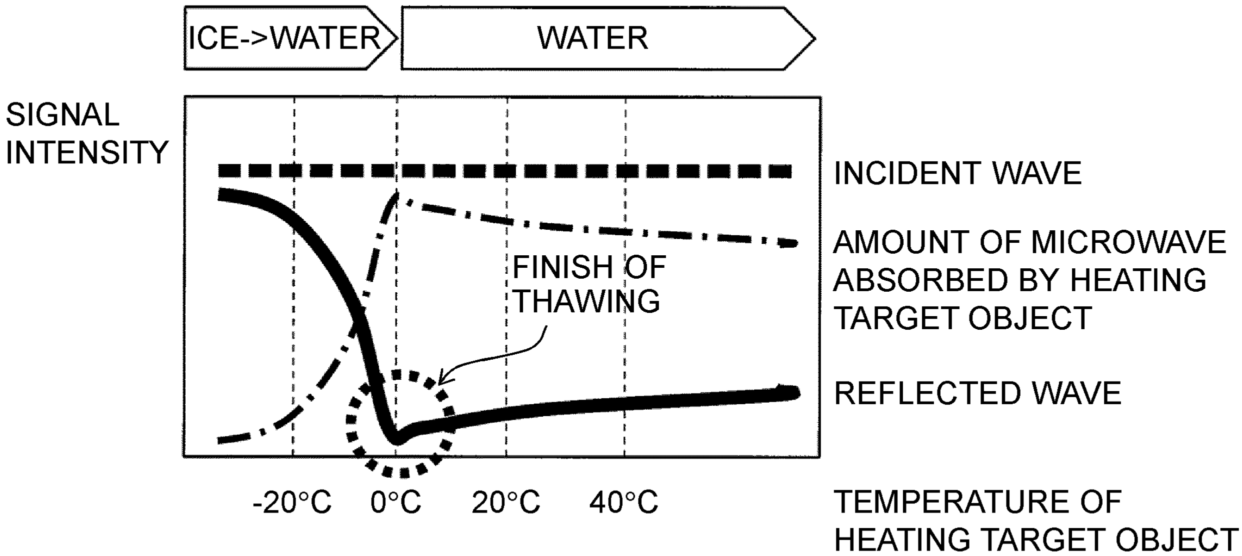

ICE->WATER
WATER
SIGNAL INTENSITY
INCIDENT WAVE
AMOUNT OF MICROWAVE ABSORBED BY HEATING TARGET OBJECT
FINISH OF THAWING
REFLECTED WAVE
-20°C
0°C
20°C
40°C
TEMPERATURE OF HEATING TARGET OBJECT

FIG. 19

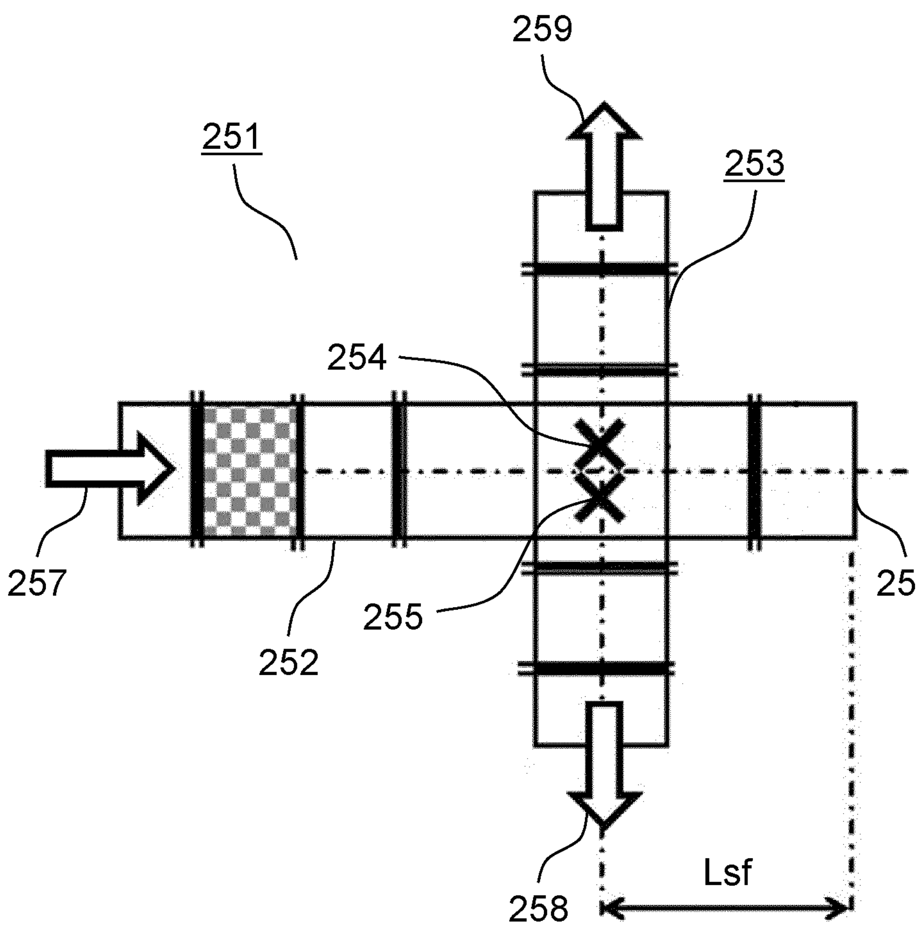


FIG. 20

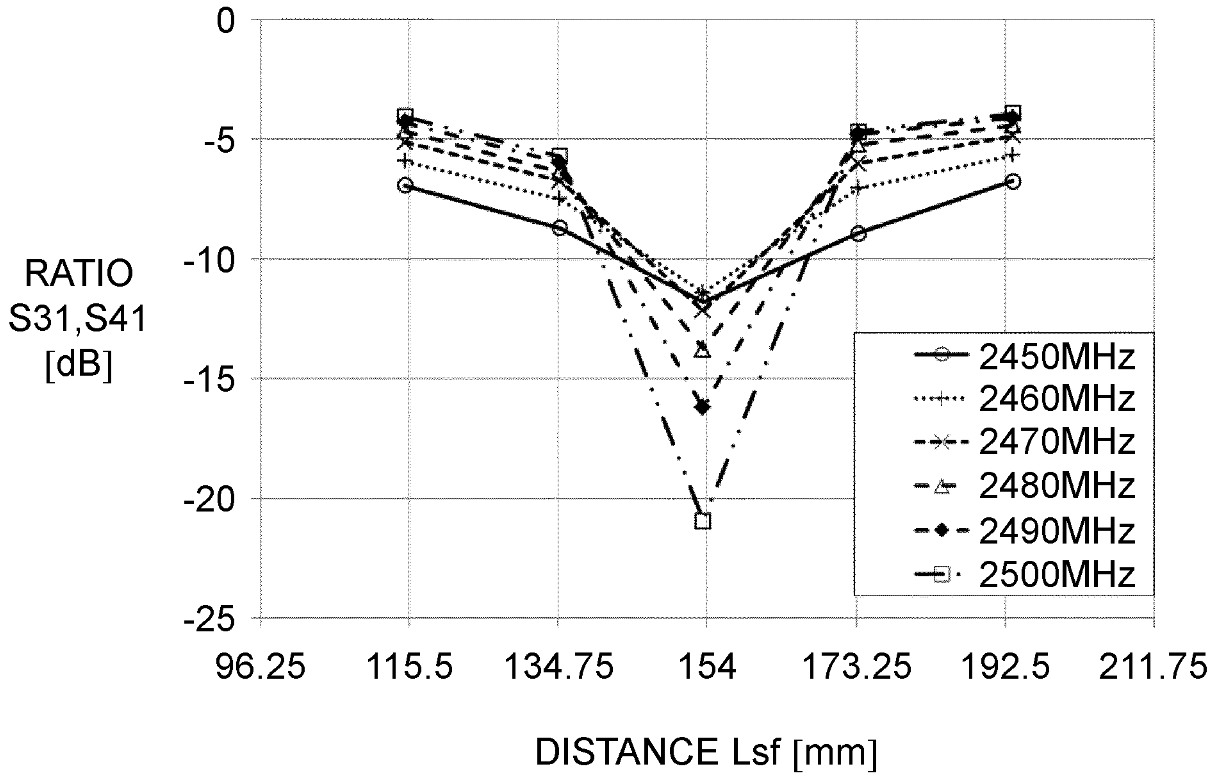
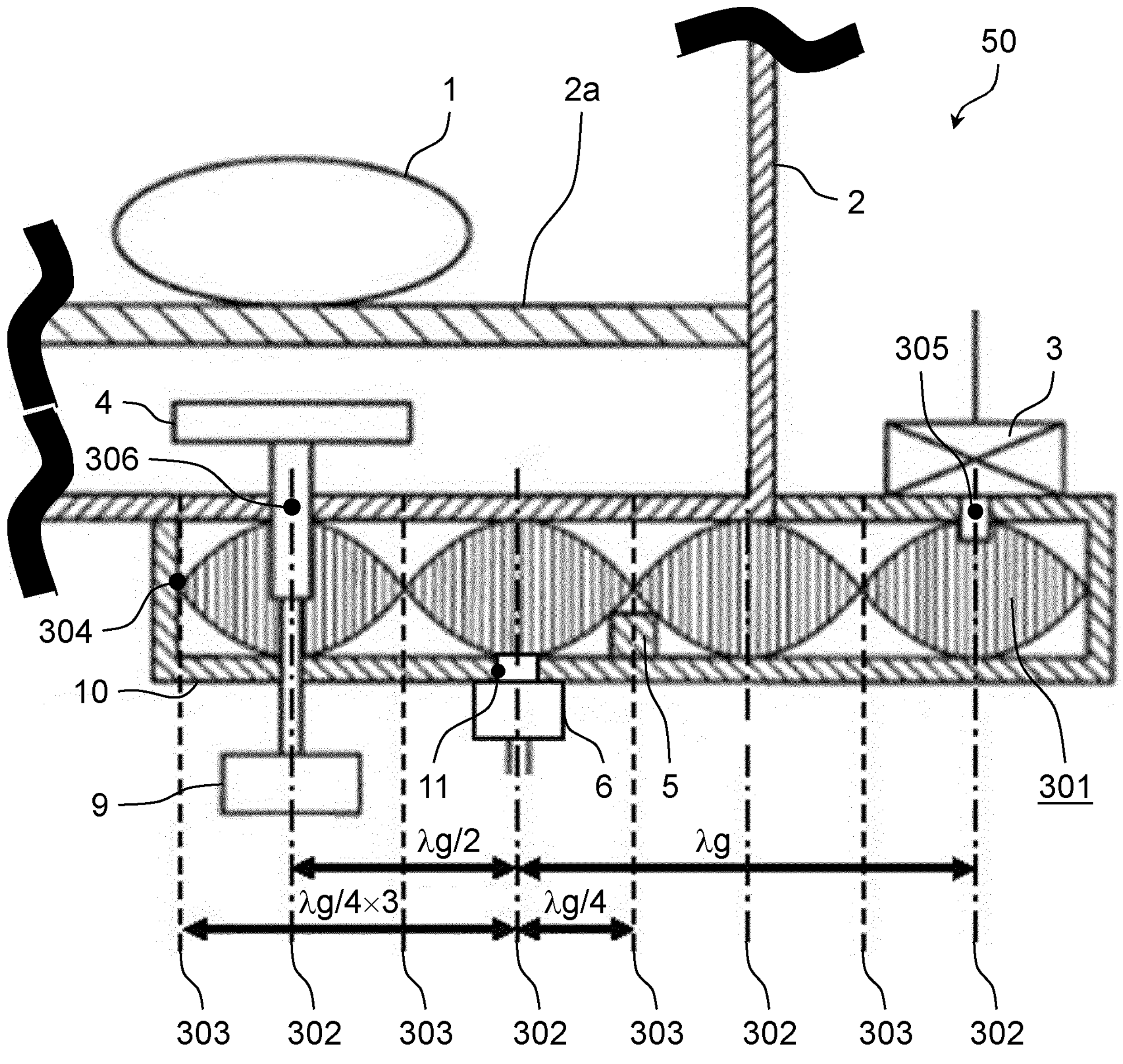

0
-5
-10
-15
-20
-25
RATIO
S31,S41
[dB]
96.25
115.5
134.75
154
173.25
192.5
211.75
DISTANCE Lsf [mm]
2450MHz
2460MHz
2470MHz
2480MHz
2490MHz
2500MHz

FIG. 21


50
1
2a
2
305
3
4
306
304
10
9
11
6
5
301
λg/2
λg
λg/4×3
λg/4
303
302
303
302
303
302
303
302

INTERNATIONAL SEARCH REPORT

International application No. PCT/JP2019/016076

A. CLASSIFICATION OF SUBJECT MATTER

Int.Cl. H05B6/74(2006.01)i, H05B6/68(2006.01)i, H05B6/70(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. H05B6/64-6/80

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	1971-2019
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 Y	JP 2014-072117 A (PANASONIC CORP.) 21 April 2014, paragraphs [0037], [0052]-[0054], [0060], fig. 1, 4, 6 (Family: none)	1-5, 9-10 6-8, 11-12
Y	JP 2014-049178 A (PANASONIC CORP.) 17 March 2014, paragraph [0028], fig. 1-2 & CN 103687122 A	6-8
Y	WO 2014/119333 A1 (PANASONIC CORP.) 07 August 2014, paragraphs [0030]-[0096], fig. 1-11 & US 2015/0244055 A1, paragraphs [0044]-[0110], fig. 1-11 & EP 2953204 A1 & CN 104604023 A	11-12

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

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"&" document member of the same patent family

Date of the actual completion of the international search 01 July 2019 (01.07.2019)	Date of mailing of the international search report 09 July 2019 (09.07.2019)
Name and mailing address of the ISA/ Japan Patent Office 3-4-3, Kasumigaseki, Chiyoda-ku, Tokyo 100-8915, Japan	Authorized officer Telephone No.

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

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Patent documents cited in the description

- JP 5816820 B **[0004]**
- JP 6176540 B **[0004]**
- JP 3331279 B **[0004]**