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(54)

Microwave heating device

(57)

The invention relates to a microwave heating device (1) comprising:

- a microwave generator (2) for generating a microwave radiation to a microwave input (4),
- at least four feeding slots (41) arranged in a first plane (P1), the microwave input (4) being connected to the cavity (10) through the feeding slots (41) so that the microwave radiation is fed into the cavity (10) through the feeding slots (41), and
- a first multi-slot resonator (5) arranged between the feeding slots (41) and the load (15) and extending in a second plane (P2) parallel to the first plane (P1), the first multi-slot resonator (5) being provided with multiple primary homogenization slots (51) arranged to divide the microwave radiation fed into the cavity (10).

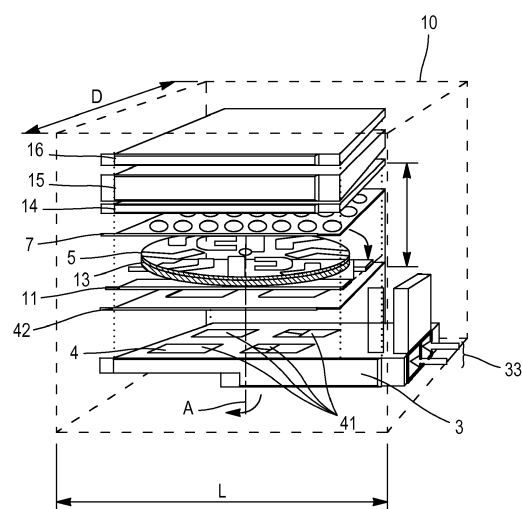


FIG. 2

DescriptionTechnical Field

[0001] The present invention generally relates to the field of microwave heating device and, more particularly, to the feeding of microwaves to a cavity in a microwave cavity for heating a load which is placed in said cavity.

Technical Background

[0002] When heating a load by means of a microwave oven, two main aspects have to be considered.

[0003] The first aspect is the efficiency of the heating process, namely the ratio between the amounts of microwave power absorbed in the load in regard to the available microwave power.

[0004] The second aspect is the uniformity of the power absorbed in the load. Indeed, microwave heating device according to the prior-art technique use relatively broadband microwave sources which are adapted to feed energy to a maximum part of the cavity of the microwave oven and excite a large number of modes and, thus, provide heating of a load that is placed in the cavity. However, interference between the propagation modes in the cavity results in places with undesirably low energy density and places with undesirably high energy density.

[0005] In order to achieve uniform heating of the load, it has also previously been suggested to use microwave stirrers or/and to place the load on a rotating plate.

[0006] These previously suggested solutions however provide insufficient control of the microwave power distribution, as they rely on the periodic modification of an inhomogeneous microwave power distribution rather than a homogeneous microwave power distribution.

[0007] In order to achieve uniform heating of the load, it has also been previously suggested to excite only one propagation mode in the cavity. This is achieved by means of a narrow-band microwave source, in combination with a careful positioning the feeding ports.

[0008] This previously suggested method however results in a low ratio between the amounts of microwave power absorbed in the load in regard to the available microwave power.

Summary of the Invention

[0009] A general object of the present invention is to provide a microwave oven in which, on the one hand, the heating of a load in the oven is more homogeneous, and, on the other hand, the heating of the load in relation to available microwave power is maximized.

[0010] This object is achieved by means of a microwave heating device comprising:

- a microwave generator for generating a microwave radiation,

- a cavity adapted to accommodate a load to be heated,

- a waveguide for guiding the microwave radiation generated by the microwave generator to the cavity,

- at least four feeding slots arranged in a first plane, the microwave input being connected to the cavity through the feeding slots so that the microwave radiation is fed into the cavity through the feeding slots, and

- a first slot resonator arranged between the feeding slots and the cavity and extending in a second plane parallel to the first plane, the slot resonator being provided with multiple homogenization slots arranged to divide the microwave radiation fed into the cavity.

[0011] It is to be noted, that the microwave heating device according to the invention, provides a homogeneous microwave power distribution, contrary to prior-art microwave heating devices which merely rely on the periodic modification of an inhomogeneous microwave power distribution.

[0012] It is also to be noted, that the microwave heating device according to the invention, provides a broadband impedance matching and is as a consequence compatible with a broadband microwave generator adapted to feed energy to a maximum part of the cavity of the microwave oven and excite a large number of modes and, thus, provide efficient heating of a load that is placed in the cavity.

[0013] The microwave heating device further comprises a second slot resonator extending in a third plane, parallel to the first plane, said second slot resonator being provided with multiple homogenization slots.

[0014] The homogenization slots of the second slot resonator being arranged in the same configuration as the homogenization slots of the first slot resonator up to a rotation of 90°.

[0015] The first slot resonator is rotatable relative to the feeding slots.

[0016] The microwave heating device further comprises strip-lines, each strip-line being positioned perpendicular to one feeding slot of the waveguide.

[0017] Each strip-line has a length equal to a wavelength of the microwave radiation.

[0018] Each strip-line is positioned between one of the feeding slots and the first slot resonator, the distance between a center of the feeding slot and a ground of the strip-line being equal to a quarter of a wavelength of the microwave radiation.

[0019] The four feeding slots are aligned by pairs in a direction of propagation of the microwave radiation in the waveguide.

[0020] The microwave heating device comprises adjustable splitters for partially obstructing two upstream

feeding slots of the four feeding slots so as to divide the microwave radiation between the upstream feeding slots and downstream feeding slots.

[0021] Each homogenization slot has a length equal to a multiple of a half-wavelength of the microwave radiation.

[0022] At least some of the homogenization slots extend from a peripheral edge of the first slot resonator.

[0023] At least some of the homogenization slots are bent with an angle equal to 120°.

[0024] At least some of the homogenization slots are bent with an angle equal to 90°.

[0025] The first slot resonator has a general circular shape having a diameter equal to a multiple of half a wavelength of the microwave radiation.

[0026] The microwave heating device further comprises an inducting slot resonator provided with circular slots, the circular slots being arranged in order to coincide with electric field maxima of the microwave radiation fed into the cavity.

[0027] At least some of the circular slots of the inducting slot resonator can be obstructed.

[0028] According to a second aspect of the invention, the invention relates to a microwave heating device comprising:

- a microwave generator for generating a microwave radiation,
- a cavity adapted to accommodate a load to be heated,
- a waveguide for guiding the microwave radiation generated by the microwave generator to the cavity,
- at least four feeding slots, the microwave waveguide being connected to the cavity through the feeding slots, and

wherein the waveguide comprises a magic-T-hybrid junction comprising an input arm for receiving the microwave radiation generated by the microwave generator, an impedance matching arm, and two output arms, the impedance matching arm being adapted to match the impedance of a reflected microwave radiation coming from the output arms, and wherein the output arms extend parallel to each other and are separated from each other by a common longitudinal central partition wall of the waveguide, the partition wall separating the microwave radiation coming from the input arm into two output microwave radiations, each output microwave radiation being fed into the cavity through the feeding slots.

[0029] The impedance matching arm extends perpendicular to the output arms.

[0030] The output arm comprises consecutively, a first portion having a first height, a first sloping section, a second portion having a second height inferior to said first height, and a second sloping section.

[0031] Two upstream feeding slots are positioned above the first sloping section and two downstream feeding slots are positioned above the second sloping section.

[0032] The four feeding slots are aligned by pairs in a direction of propagation of the microwave radiation in the two output arms.

[0033] The microwave heating device comprises adjustable splitters for partially obstructing two upstream feeding slots of the four feeding slots so as to divide the microwave radiation between the upstream feeding slots and downstream feeding slots.

[0034] The microwave heating device further comprises matching screws capable of being gradually introduced in the input arm of the waveguide so as to match an impedance of the waveguide with an impedance of the load to be heated.

Brief Description of the Drawings

[0035] In the following, a number of preferred embodiments of the invention will be described in more detail. In the detailed description references are made to the accompanying drawings, in which

- Fig. 1 is a general view of a microwave oven in accordance with the present invention,
- Fig. 2 is exploded view of the microwave oven shown in Fig. 1,
- Fig. 3 is a block diagram representation of the functioning of the microwave oven shown in Fig. 1,
- Fig. 4a is exploded view of a first embodiment of a microwave in accordance with the present invention,
- Fig. 4b to Fig. 4e are top plan views of various possible slots configurations of the resonator slot of the microwave oven shown in Fig. 4a,
- Fig. 5a is exploded view of the microwave oven shown in Fig. 1,
- Fig. 5b is a top plan view of resonator slot of the microwave oven shown in Fig. 5a,
- Fig. 6 is a schematic top plan view of the microwave input of the microwave oven shown in Fig. 1,
- Fig. 7 is a cross section view in a plan containing the axis of the central partition wall of the waveguide of the microwave input which is shown in Fig. 6,
- Fig. 8a is a cross section view in a plan perpendicular to the axis of the central partition wall of the waveguide of the microwave input which is shown in Fig. 6,
- Fig. 8b shows a magic-T-hybrid junction of the microwave oven shown in Fig. 1,
- Fig. 9 is a cross section view in a plan containing the axis of the central partition wall of the waveguide of the microwave input which is shown in Fig. 6, having two diagrams of the voltage standing wave ratio (VSWR) over the length of the waveguide and the impedance matching arm of the magic T
- Fig. 10a to 10c are top plan views of various possible

slots configurations of the resonator slot of the microwave oven shown in Fig. 1,

- Fig. 11 is a top plan view of possible slots configurations of the inducting slot resonator of the microwave oven shown in Fig. 1.
- Fig. 12 is a top plan view of possible slots configurations of the inducting slot resonator having a couple of the circular slots shortcircuited.
- Fig. 13 are thermographics views of the temperature distribution in the load, A1, B1, C1 and D1 in a microwave oven without homogenization system according to the invention, A2, B2 and C2 in a microwave oven with an homogenization system according to a first embodiment of the invention comprising a rotation slot resonator, and A3, B3 and C3 in a microwave oven with an homogenization system according to a second embodiment of the invention comprising a two slices slot resonator.

Description of the Invention

[0036] In the following, the 'wavelength' refers to the wavelength of the microwaves traveling along a waveguide in the medium, the wavelength in the medium being defined as $\lambda_g = \lambda_o / [1 - (\lambda_o / \lambda_c)^2]^{0.5}$, where λ_o is the free space wavelength measured in vacuum rather than in the medium, and λ_c is the cutoff frequency waveguide frequency (the lowest frequency that can propagate in the waveguide). In the described embodiments, $\lambda_o = 121.45\text{mm}$, and $\lambda_c = 2 \cdot La = 184\text{mm}$, La being the broad dimension of the waveguide section.

[0037] As illustrated in Fig. 1, the microwave oven 1 comprises a microwave generator 2, a cavity 10, a waveguide 3 and a multilayer resonator structures or photonic crystal 50.

[0038] The microwave generator 2 is operatively connected to the cavity 10 through the waveguide 3, the waveguide 3 being provided with a microwave input 4, through which microwaves are to be fed to the cavity 10.

[0039] The microwave generator 2 generates a microwave radiation at a microwave radiation wavelength to the microwave input 4.

[0040] As shown in fig. 3, the microwave oven 1 further comprises an isolator 21 and a control circuit 20.

[0041] The isolator 21 transmits microwave in one direction only. It is used to shield the microwave generator 2 on its input side, from the effects of conditions on its output side, in particular to prevent the microwave generator 2 being detuned by a mismatched load 15.

[0042] As illustrated in fig. 3, the isolator 21 comprises two directional couplers, one for the reflected wave 18 and the other for the direct wave 19.

[0043] The reflected wave and the direct wave are used in the control circuit 20 in order to adapt the power generated by the microwave generator 2 to the load 15.

The cavity

[0044] The cavity 10 is adapted to accommodate a load 15 to be heated. The load 15 can either be a solid or a liquid sample.

[0045] As illustrated in fig. 1, the load 15 is typically placed between the multilayer resonator structures 50 and a metallic plate 16.

[0046] As illustrated in fig. 2, the microwave oven advantageously further comprises a dielectric plate 14 positioned between the multilayer resonator structures 50 and metallic plate 16 and adapted to support the load 15.

[0047] The cavity 10 is surrounded by walls made out of a conductive material in order to prevent the emission of radiation to the outside for protection of the user.

[0048] The cavity 10 is a resonator in which the microwave power is distributed throughout the volume of the cavity 10. The microwave power distribution depends on the resonance mode generated in the cavity, the number of maxima in each direction being determined by a ratio between this dimension and the half-wavelength.

[0049] The resonances modes and, implicitly, the distribution of the microwaves are determined by the combination of incoming waves and reflected waves reflected on the walls of the cavity 10. The resonances modes depend on the size, shape and volume of the cavity 10, the nature and volume of the load 15 and the distribution of the microwave input 4. The size, shape and volume of the cavity 10 and the distribution of the microwave input 4 are adapted to the nature and volume of the load 15 in order to maximize the resonances generated in the cavity 10.

[0050] In practice, the cavity dimensions (namely its length L and depth D and the height H) are in the order of hundred microwave wavelengths, namely approximately in the order of 50cm.

The waveguide

[0051] The waveguide 3 is adapted for guiding the microwave radiation generated by the microwave generator 2 to the microwave input 4.

[0052] As illustrated in Fig. 1, the waveguide 3 comprises an input arm 31 for receiving the microwave radiation generated by the microwave generator 2, an impedance matching arm 32, and two output arms 33. These output arms 33 can be identical.

[0053] Each arm of the waveguide is a hollow metallic tube of rectangular transverse section. Each arm of the waveguide 3 consists of two opposite broad walls and two opposite narrow walls, the dimension of the broad walls in the transversal plan being the larger dimension of the waveguide section, while the dimension of the narrow walls in the transversal plan is the smaller dimension W_p of the waveguide section.

[0054] Each arm of the waveguide has the same section. In particular the larger dimension of the waveguide section L_t of the impedance matching arm 32 is equal to

the larger dimension of the waveguide section La of the output arms 31.

[0055] In order to maximize the power that can propagate inside the waveguide 3 before a dielectric breakdown occurs, the smaller dimension of the waveguide section is preferably half the larger dimension of the waveguide section.

[0056] The smaller dimension of the section of the waveguide is equal to a quarter of the microwave wavelength, while the larger dimension of the section of the waveguide is equal to half the microwave wavelength. The microwave half-wavelength being approximately equal to 80mm, the larger dimension of the section of the waveguide is equal to 40mm, while the smaller dimension of the section of the waveguide is equal to 20mm.

[0057] The modes supported by a waveguide are quantized. The allowed modes can be found by solving Maxwell's equations for the boundary conditions on the walls of the waveguide 3.

[0058] In particular, the wave in the waveguide 3 must have zero tangential electric field amplitude at the walls of the waveguide, so the transverse pattern of the electric field of waves is restricted to those that fit between the walls of the cavity 10.

The microwave input

[0059] As illustrated in fig. 2, the microwave input 4 is a slot antenna consisting of a metal surface, typically a flat plate arranged in a first plane P1 included in the broad wall of the output arms 31, with at least four feeding slots 41 cut out.

[0060] The microwave input 4 is connected to the cavity 10 through the feeding slots 41 so that the microwave radiation is fed into the cavity 10 through the feeding slots 41.

[0061] The feeding slots 41 are arranged so that each one of the feeding slots 41 feeds the same amount of power to the cavity 10 and so that the power fed by the feeding slots 41 to the cavity 10 is maximized.

[0062] As illustrated in fig. 6, this is achieved by ensuring that each of the feeding slots 41 has a width Wf less than a 1/4-wavelength of the microwave radiation. Each of the feeding slots 41 has preferably a length equal to the transversal waveguide dimension..

[0063] As illustrated in fig. 9, and in order to further maximize the power radiated by each feeding slot 41, each feeding slot 41 extends from a maximum of the electric field to a minimum of the electric field, in the direction of the propagation of the microwave radiation.

[0064] As illustrated in fig. 6 and fig. 7, the generator 5 is connected to the feeding slots 41 by means of strip-lines 11. Each feeding slot 41 of the waveguide is associated with one strip-line 11.

[0065] The strip-lines 11 are flat strips of metal sandwiched between two parallel ground planes, supported by an insulating plate forming together a dielectric.

[0066] To prevent the propagation of unwanted

modes, the two ground planes are shorted together. This is commonly achieved by a row of vias running parallel to the strip on each side.

[0067] The central conductor need not be equally spaced between the ground planes. If a dielectric low loss material is used in the strip line circuit, other than air, then the dielectric material may be different above and below the central conductor.

[0068] The strip-lines 11 are positioned between one of the feeding slots 41 and the first slot resonator 5. The strip-lines 11 comprise a straight section and two mounting brackets, conductive short circuit, mounted on each side of the associated feeding slot 41. The strip-lines 11 are mounted across and perpendicular to the associated feeding slot 41 of the waveguide.

[0069] The upper conductive wall of the waveguide 33 is electrically connected (namely short circuited with vias around the slots perimeter with $\square/8$ distance between each via) with the antenna 4.

[0070] Each of the strip lines are short circuited to the ground at both extremities (the metal of the strip is bend at 90° at the extremity connected to the ground, this ground being common with the two ground plane of the antenna 4 and of the waveguide 33).

[0071] The strip-lines extremities, the antenna 4 and the waveguide 33 are connected together with a short-circuit-vias.

[0072] The antenna 4 has typically a dimension of 350mmx350mm and the short-circuiting vias are typically 160mm large. If those short circuit connections are of low quality then local heat can occur between grounds, up to melting the metal.

[0073] The width of the strip, the thickness of the substrate and the relative permittivity of the substrate are chosen in order to adapt the impedance of the strip to the feeding slot 41, in order to divide in two the power fed by the associated feeding slot 41.

[0074] Each strip-line 11 has a symmetry line 110 located on its longitudinal axis Algt.

[0075] The strip-lines 11 have a specific width Ws calculated with the strip line theory model.

[0076] As illustrated in fig. 6, the distance SL1 between the lateral axis Alat of the feeding slot 41 and a symmetry line 110 of the strip-line 11 is less than a quarter of a wavelength of the microwave radiation, the exact value being determined by empirical methods.

[0077] As illustrated in fig. 6, the distance SL2 between the longitudinal axis Algt and the near end of the strip-line 11 is equal to a quarter of a wavelength of the microwave radiation.

[0078] As illustrated in fig. 6, the feeding slots 41 are preferably aligned by pairs in a direction of propagation of the microwave radiation in the waveguide 3.

[0079] In the configuration comprising four feeding slots 41, two of the feeding slots 41 are positioned upstream and two of the feeding slots 41 are positioned downstream.

[0080] As illustrated in fig. 6, in order to equally divide

the power between the upstream feeding slots 41 and the downstream feeding slots 41, the distance between the far end of the upstream feeding slots 41 and the downstream feeding slots 41 is equal to the free space wavelength.

[0081] As illustrated in fig. 7, in order to maximize the power radiated by the feeding slots 41, the distance between the far end of the upstream feeding slots 41 and the input arm 31 is equal to a multiple of an eighth of the wavelength.

[0082] As illustrated in fig. 6 and fig. 7, the microwave heating device preferably further comprises adjustable splitters 42 for partially obstructing two upstream feeding slots 41 of the four feeding slots 41, each upstream feeding slot 41 of the waveguide being associated with one splitter 42.

[0083] The position of the splitter 42 is adapted so as to divide equally the microwave radiation between the upstream feeding slots 41 and downstream feeding slots 41.

[0084] In practice and as illustrated in fig. 7, each splitter 42 has the form of a shutter fastened on one of its side to the far end of the feeding slot 41 and extending inside the output arm 33. Thus the splitters 42 are adapted to be adjustably angled in regard to the feeding slot 41 so as to adjust the power radiated by the upstream feeding slot 41, in order to equally divide the microwave radiation between the upstream feeding slots 41 and downstream feeding slots 41.

T-hybrid junction

[0085] As illustrated in fig. 8a and 8b, and as described above, the waveguide 3 comprises an input arm 31 for receiving the microwave radiation generated by the microwave generator 2, an impedance matching arm 32, and two output arms 33. The input arm 31, the impedance matching arm 32, and the two output arms 33a are practically the pseudo-magic T of the T-hybrid junction 35. This pseudo-magic T junction differs from theoretical magic T by the matching arm 32 which operate in electric E mode. The T-hybrid junction 35 will be described in details in the following paragraphs.

[0086] As illustrated in Fig. 8b, the output arms 33 extend parallel to each other and are separated from each other by a longitudinal central partition wall 34 of the waveguide. The partition wall 34 separates the microwave radiation coming from the input arm 31 into two output microwave wave, each output microwave radiation being fed into the cavity 10 through two of the feeding slots 41.

[0087] As described before, the waveguide 3 is a rectangular section tube consisting of two opposite broad walls and two opposite narrow wall.

[0088] As illustrated in fig. 8b, the impedance matching arm extends perpendicular to the broad wall of the input arm. The narrow wall of the impedance matching arm 32 is parallel to the narrow wall of the input arm 31, while

the broad wall of the impedance matching arm 32 is parallel to the broad wall of the input arm 31.

[0089] As illustrated in fig. 8a, the longitudinal central partition wall 34 extends in the longitudinal axis of the input arm 31 and is parallel to the narrow wall of the input arm 31. The longitudinal central partition wall 34 constitutes a common narrow wall for each of the output arms 32. The output arms 33 extend in the longitudinal axis of the input arm 31 (namely perpendicular to the transversal section of the input arm 31), the impedance matching arm therefore extending perpendicular to the broad wall of the output arms 33

[0090] As illustrated in Fig. 9, the T-hybrid junction 35 advantageously comprises a T-hybrid junction splitter 36, adapted to equally divide the power reflected from each output arm 33 between the input arm 31 and the impedance matching arm 32.

[0091] In practice, the T-hybrid junction splitter 36 is a shutter fastened on one of its side to the output arms wall facing the impedance matching arm 32. The angle between T-hybrid junction splitter 36 and the output arms wall facing the impedance matching arm 32 is adjusted in order that the power reflected from each output arm 33 divides equally between the input arm 31 and the impedance matching arm 32.

[0092] The angle between T-hybrid junction splitter 36 and the output arms wall facing the impedance matching arm 32 is typically comprised between 10 and 45°.

[0093] In practice, the distance between the input arm 31 and the fastened side of the T-hybrid junction splitter 36 is equal to 3/8 wavelength, in order to ensure that the superposition of the wave incoming from the input arm 31 and the reflected wave reflected in the impedance matching arm 32 is destructive.

[0094] As illustrated in fig. 8b, the electric field E of the dominant mode in each arm is perpendicular to the broad wall of the arm, while the magnetic field of the dominant mode in each arm is perpendicular to the narrow wall of the arm.

[0095] The matching arm 32 is a transverse magnetic (TM) modes waveguide, namely there is no magnetic field in the direction of propagation. A transverse magnetic (TM) modes waveguide is also called E modes because there is only an electric field along the direction of propagation.

[0096] As illustrated in fig 8b, the arrangement of the impedance matching arm 32 and the input arm 31 is such that the electric field E of the dominant mode in the impedance matching arm 32 is perpendicular to the electric field E of the dominant mode in the input arm 31 as well as to the electric field of the dominant mode in the output arms 33.

[0097] As the impedance matching arm 32 extends from the input arm 31 in the same direction as the E-field propagating in the waveguide, the electric field in the impedance matching arm 32 and the electric field in the input arm 31 are 180° out of phase with each other.

[0098] As the impedance matching arm 32 is further

adapted to match the impedance of a reflected microwave radiation coming from the output arms 33, for a wave entering the input arm 31, the impedance matching arm 32 prevents any of the power being reflected back out of the input arm 31.

[0099] To that effect, the impedance matching arm 32 is a dead end and its length (namely its dimension in its longitudinal axis) is adapted so that the reflected wave reflected at the dead end of the impedance matching arm 32 is in opposition of phase with the incoming wave at the junction 35.

[0100] In practice, and as illustrated in fig. 9, the impedance matching arm 32 has a length of 7/8 of the microwave wavelength.

[0101] The output arms 33 are symmetrical so that the superposition of the wave incoming from the input arm 31 and the reflected wave reflected in the impedance matching arm 32 is destructive.

[0102] As the impedance matching arm 32 eliminates any reflection in the input arm 31, and considering the symmetry of the output arms 33, the power is equally divided between the two output arms 33.

[0103] Reciprocally, the input arm 31 and the impedance matching arm 32 are matched, so that the output arms 33 are isolated from one another and the power reflected from each output arm 33 divides equally between the input arm 31 and the impedance matching arm 32.

[0104] The isolation between the two output arms 33 is wide-band and is as perfect as is the symmetry of the device. The isolation between the collinear output arms 33 is however limited by the performance of the matching structure.

[0105] The T-hybrid junction as described above is advantageously combined with the output arms as described below, however it is to be understood that those two aspects can be implemented alone and prove both to be advantageous independently.

Output arms

[0106] As illustrated in Fig. 7, each of the outputs arms 33 comprises consecutively, a first portion 331 having a first height G1, a first sloping section 332, a second portion 333 having a second height G2 inferior to said first height, and a second sloping section 334, the height of the output arms being defined as the narrow dimension of the transverse section of the waveguide.

[0107] The first height G1 is typically a % of a wavelength while the second height is a 1/8 of the wavelength.

[0108] The two upstream feeding slots 41 are positioned above the first sloping section 332 and two downstream feeding slots 41 are positioned above the second sloping section 334.

[0109] As illustrated in Fig. 9, in order to maximize the power radiated by the feeding slots 41, the junction between the first portion 331 of the output arm and the first sloping section 332 is located at a maximum of the elec-

tric field while the junction between the first sloping section 332 and the second portion of the output arm 331 is located at a minimum of the electric field.

[0110] Similarly, and as illustrated in Fig. 9, the junction between the second portion 331 of the output arm and the second sloping section 332 is located at a maximum of the electric field while the far end of the output arm 33 is located at a minimum of the electric field.

[0111] The wave propagation in the first section 331 of the output arm 33 is first reflected on the first sloping section 332 in the direction of the upstream feeding slot 41 and is partly reflected on the splitter 42. The splitter 42 divides the radiation in two. The first part of the power of the radiation reaches the upstream feeding slot 41 and is radiated through it. The second part of the power of the radiation is reflected on the splitter 42 in the direction of the second portion 333 of output arm 33, reaches the downstream feeding slot 41 and is radiated through the downstream feeding slot 41.

[0112] The microwave heating device further comprises matching screws 39 capable of being gradually introduced in the input arm 31 of the waveguide so as to match the impedance of the waveguide 3 with an impedance of the load 15 to be heated.

The multilayer resonator structure or photonic crystal

[0113] The first multi-slot resonator 5 (fig.2) is a slot antenna consisting of a metal surface extending in a second plane P2 parallel to the first plane P1 comprising the feeding slots 41.

[0114] As illustrated in Fig. 2, the multi-slot resonator 5 is advantageously supported by a dielectric plate 13.

[0115] The first multi-slot resonator 5 is a flat plate with multiple primary homogenization slots 51 cut out. The primary homogenization slots 51 are arranged so as to disseminate the microwave radiation fed into the next layer of inducting slots 7.

[0116] As illustrated in Fig. 4b to 4c, the multi-slot resonators 5 and 6 have a general circular shape having a diameter equal to a multiple of half a wavelength of the microwave radiation.

First embodiment of the slot resonator: two slice slot resonator

[0117] As illustrated in Fig. 4a, in a first embodiment, the microwave heating device 1 further comprises a second multi-slot resonator 6.

[0118] The second multi-slot resonator 6 consists of a metal surface, typically a flat plate extending in a third plane, parallel P3 to the first plane, with multiple secondary homogenization slots 61 cut out.

[0119] As illustrated in Fig. 4b to 4e, the second multi-slot resonator 6 is a slot antenna identical to the first multi-slot resonator 5 and the secondary homogenization slots 61 are arranged in the same configuration as the primary homogenization slots 51 of the first multi-slot resonator

5 up to a rotation of 90°.

[0120] The first multi-slot resonator 5 and the second multi-slot resonator 6 are motionless.

[0121] The superposition of two multi-slot resonators 5 and 6 provided with an identical pattern of slots up to a rotation of 90° significantly improves the homogeneity of the radiated microwave power.

[0122] Second embodiment of the slot resonator: rotatable slot resonator

[0123] As illustrated in Fig. 5a, in a second embodiment, the first multi-slot resonator 5 is rotatable relative to microwave input 4.

[0124] In this embodiment, the microwave oven further comprises rotation motor 55 rotationally driving the first multi-slot resonator 5 in the second plane, about a vertical axis A1 passing through its center, and typically at a rotation speed w comprised between 90 and 120 revolutions per minute (rpm).

[0125] The rotation of the multi-slot resonator 5 significantly improves the homogeneity of the radiated microwave power.

Disposition of the homogenization slots

[0126] In the first as well as the second embodiment, the homogenization slots 51, 61 shape and size are designed in order to maximize the diffusion of the microwave power.

[0127] The multi-slot resonators 5 and 6 are capacitive slot resonators, which mean that the homogenization slots 51, 61 are arranged in order to coincide with the local electric field nodes of the microwave radiation fed into the cavity 10.

[0128] As illustrated in Fig. 4b to 4e, and 5b, in order to, maximize the power radiated by each homogenization slot 51, 61, each of them has a length equal to a multiple of a half-wavelength of the microwave radiation.

[0129] As illustrated in Fig. 4b to 4c, and 5b, some of the homogenization slots 51, 61 extend from a peripheral edge of the multi-slot resonator 5 or 6, while others don't. The effects of those open slots are the same as those of a radial open antenna, namely to disperse the microwaves outside of the circular multi-slot resonators 5.

[0130] As illustrated in Fig. 4b to 4e, and 5b, at least some of the homogenization slots 51, 61 are bent with an angle equal to 120°.

[0131] As illustrated in Fig. 4b to 4e, and 5b, some of the other homogenization slots 51, 61 are bent with an angle equal to 90°. Those homogenization slots 51 are typically U-shaped slots. The effects of those slots are to disperse de microwaves inside the multi-slot resonators 5, in the central zone of the photonic crystal.

[0132] Alternatively, As illustrated in Fig. 10c, the homogenization slots 51 are circular slots with a diameter $Dr3$ equal to a half wavelength.

Inducting slot resonator

[0133] As illustrated in Fig. 2, the microwave heating device 1, and more exactly the photonic crystal 50, further comprises an inducting slot resonator 7 positioned between the load 15 and the multi-slot resonator 5.

[0134] The inducting slot resonator 7 is provided with circular slots 71.

[0135] As illustrated in Fig. 11, the circular slots are arranged in order to coincide with the local electric field maxima of the microwave radiation fed into the cavity 10 so as to uniformly disperse de microwaves under de load support 14 and the load itself 15. The diameter of the circular slots of the inducting slot resonator 7 is less than a quarter of a wavelength of the microwave radiation.

[0136] As illustrated in Fig. 12, when some of the local electric field maxima are superior to the other local electric field maxima, the circular slots of the inducting slot resonator 7 corresponding to those local electric field maxima are selectively obstructed, in order to correct any inhomogeneity of the radiated power.

[0137] The slot resonator as described above is advantageously combined with the T-hybrid junction as described below, however it is to be understood that those two aspects can be implemented alone and both prove to be advantageous independently.

[0138] The microwave heating device according to the invention provides a homogeneous microwave power distribution. For a liquid load having a volume of 3L to 6L, the difference of temperature through the load is inferior to 3°C for a general temperature elevation of 25°C (between 20°C and 45°C).

Claims

1. Microwave heating device (1) comprising:

- a microwave generator (2) for generating a microwave radiation to a microwave input (4),
- a cavity (10) adapted to accommodate a load (15) to be heated,
- a waveguide (3) for guiding the microwave radiation generated by the microwave generator (2) to the cavity (10),
- at least four feeding slots (41) arranged in a first plane (P1), the microwave input (4) being connected to the cavity (10) through the feeding slots (41) so that the microwave radiation is fed into the cavity (10) through the feeding slots (41), and
- a first multi-slot resonator (5) arranged between the feeding slots (41) and the load (15) and extending in a second plane (P2) parallel to the first plane (P1), the first multi-slot resonator (5) being provided with multiple primary homogenization slots (51) arranged to divide the microwave radiation fed into the cavity (10).

2. Microwave heating device (1) according to claim 1, wherein the microwave heating device (1) further comprises a second multi-slot resonator (6) extending in a third plane, parallel (P3) to the first plane, said second multi-slot resonator (6) being provided with multiple secondary homogenization slots (61). 5
3. Microwave heating device (1) according to claim 2, the secondary homogenization slots (61) of the second multi-slot resonator (6) being arranged in the same configuration as the primary homogenization slots (51) of the first multi-slot resonator (5) up to a rotation of 90°. 10
4. Microwave heating device (1) according to claim 1, wherein the first multi-slot resonator (5) is rotatable relative to the feeding slots (41). 15
5. Microwave heating device according to one of claims 1 to 4, wherein the microwave heating device (1) further comprises strip-lines (11), each strip-line (11) being positioned perpendicular to one feeding slot (41) of the waveguide. 20
6. Microwave heating device according to claim 5, wherein each strip-line (11) has a length equal to a wavelength of the microwave radiation. 25
7. Microwave heating device according to one of claims 1 to 6, wherein each strip-line (11) is positioned between one of the feeding slots (41) and the first multi-slot resonator (5), the distance between a center of the feeding slot (41) and a symmetry line (110) of the strip-line (11) is less than a quarter of a wavelength of the microwave radiation. 30
8. Microwave heating device (1) according to one of claims 1 to 7, wherein each homogenization slot (51, 61) has a length equal to a multiple of a half-wavelength of the microwave radiation. 35
9. Microwave heating device (1) according to one of claims 1 to 8, wherein the first multi-slot resonator (5) has a general circular shape having a diameter equal to a multiple of half a wavelength of the microwave radiation. 40
10. Microwave heating device (1) according to one of claims 1 to 9, further comprising an inducting slot resonator (7) provided with circular slots (71), the circular slots being arranged in order to achieve a uniform dispersion of the microwaves in the cavity (10). 45
11. Microwave heating device (1) according to claims 10, wherein at least some of the circular slots of the inducting slot resonator are obstructed. 50
12. Microwave heating device (1) according to one of preceding claims, the waveguide comprising a pseudo-magic-T-hybrid junction (35) comprising:
 - an input arm (31) for receiving the microwave radiation generated by the microwave generator (2),
 - an impedance matching arm (32),
 - two output arms (33),
 the impedance matching arm (32) being adapted to match the impedance of a reflected microwave radiation coming from the output arms (33), and wherein the output arms (33) extend parallel to each other and are separated from each other by a common longitudinal central partition wall (34), the partition wall (34) equally separating the incoming microwave radiation into the two output arms (33). 55
13. Microwave heating device (1) according to the preceding claim, the impedance matching arm (32) extending perpendicular to the output arms (33).
14. Microwave heating device (1) according to one of claims 12 to 13, the output arms (31) consecutively comprising, a first portion (331) having a first height, a first sloping section (332), a second portion (333) having a second height inferior to said first height, and a second sloping section (334), two upstream feeding slots (41) being positioned above the first sloping section (331) and two downstream feeding slots (41) being positioned above the second sloping section (334).
15. Microwave heating device (1) according to one of the preceding claims, comprising adjustable splitters (42) for partially obstructing two upstream feeding slots (41) of the four feeding slots (41) so as to equally divide the microwave radiation between the upstream feeding slots (41) and the downstream feeding slots (41).

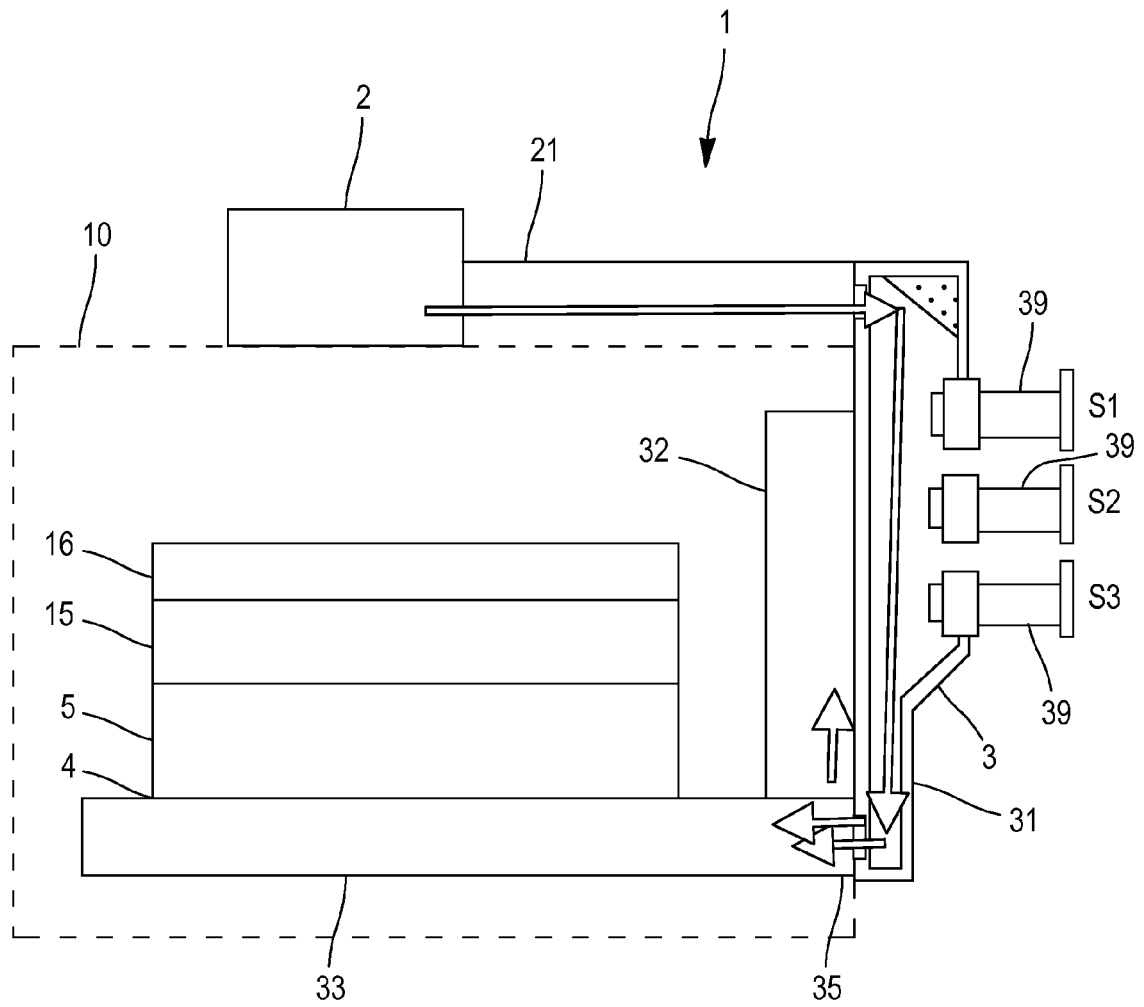


FIG. 1

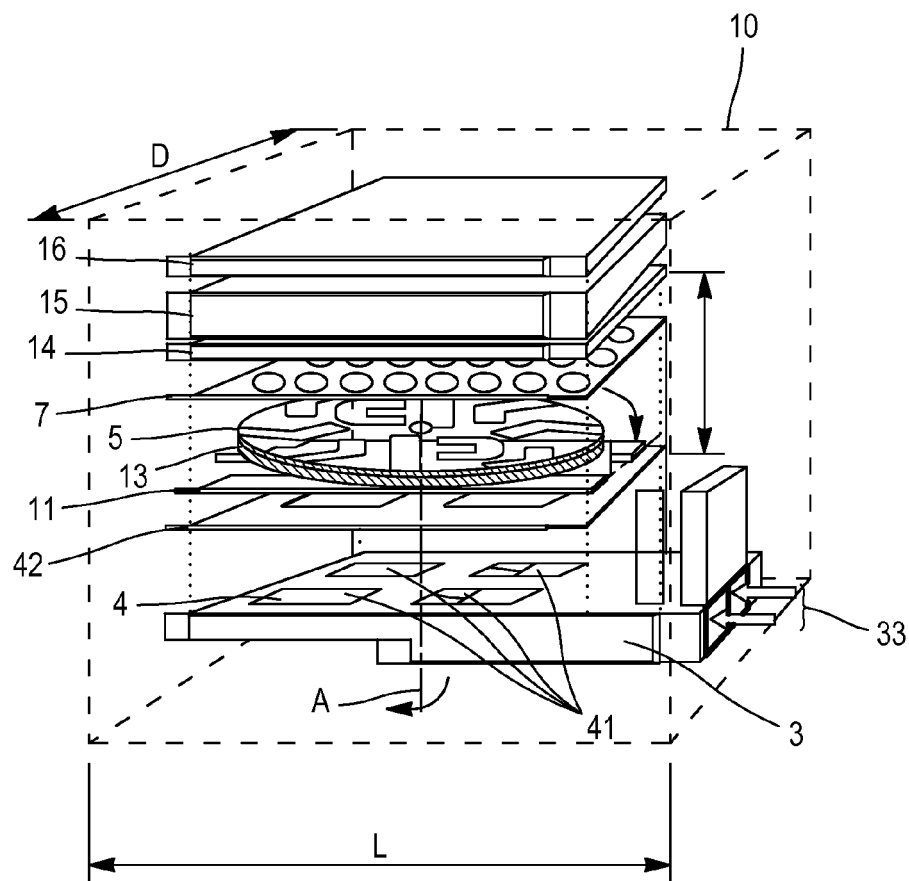


FIG. 2

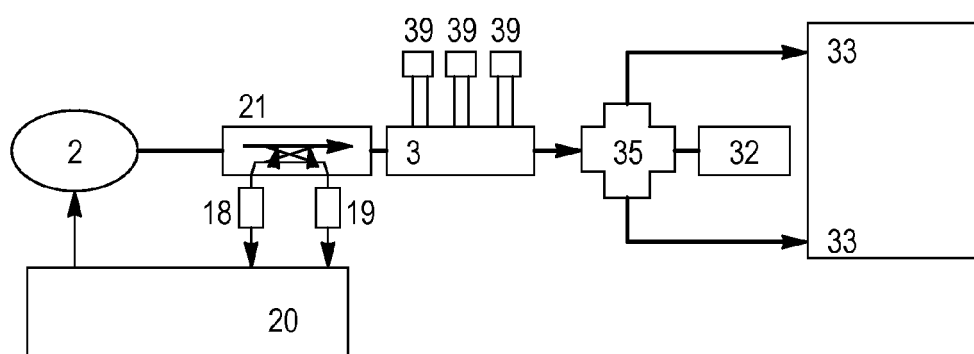


FIG. 3

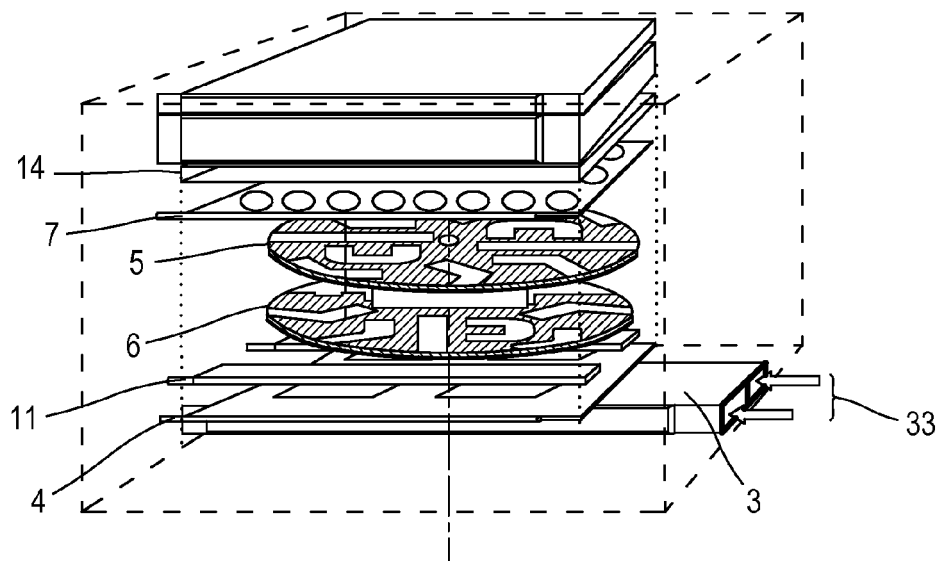


FIG. 4a

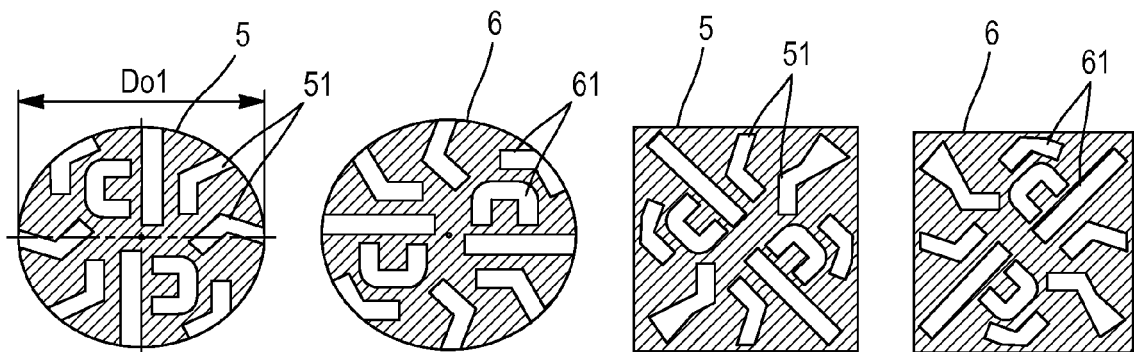
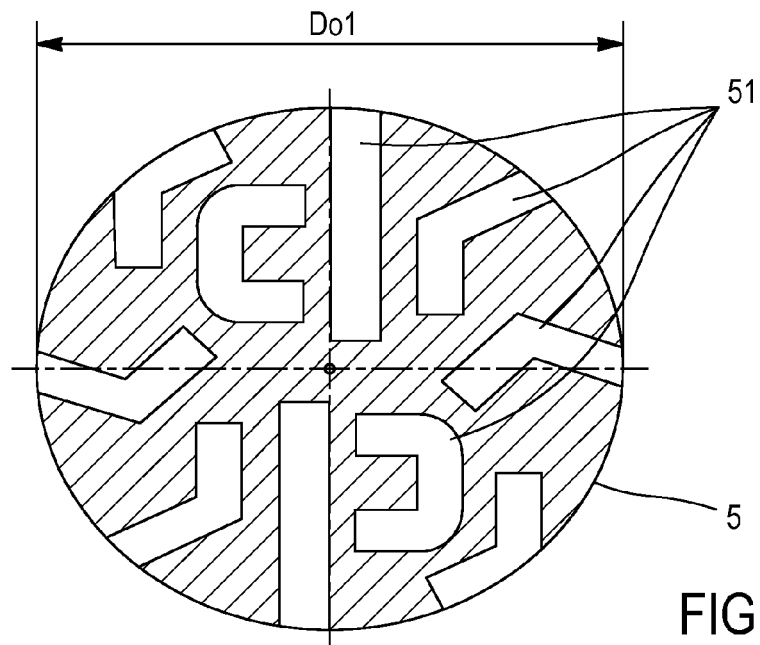
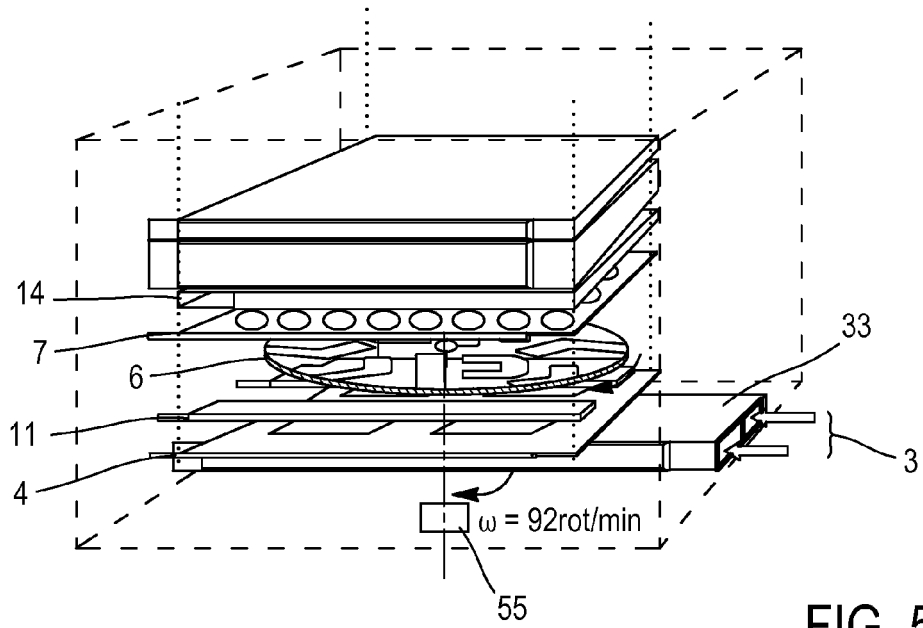


FIG. 4b

FIG. 4c

FIG. 4d

FIG. 4e



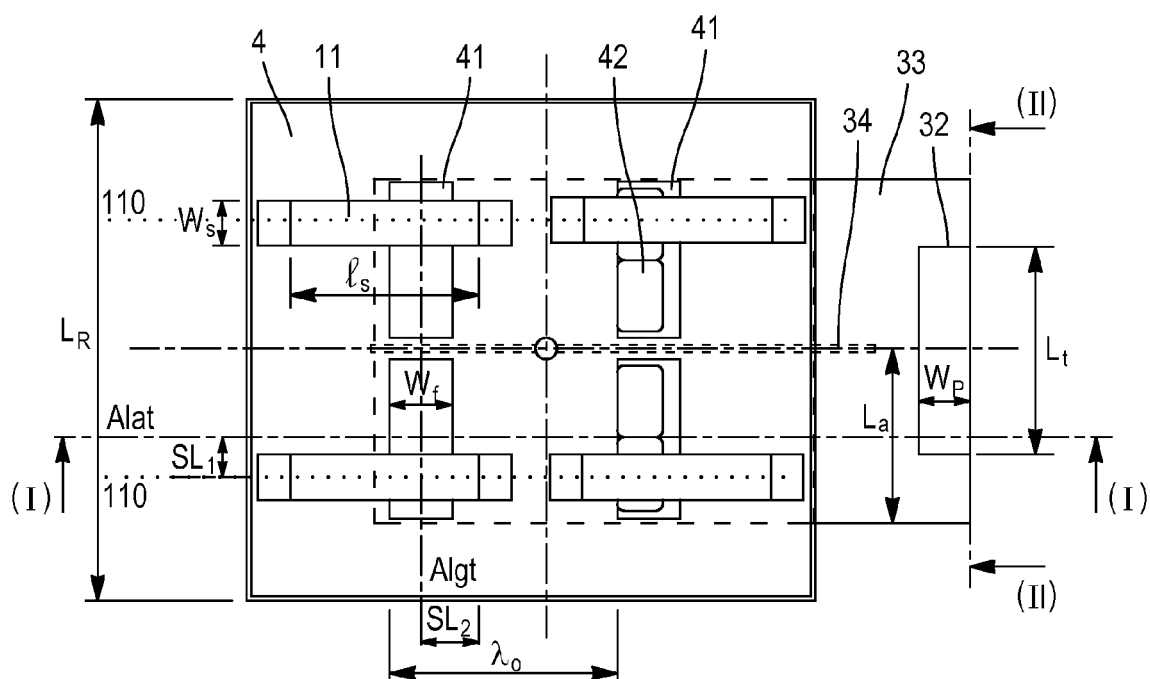


FIG. 6

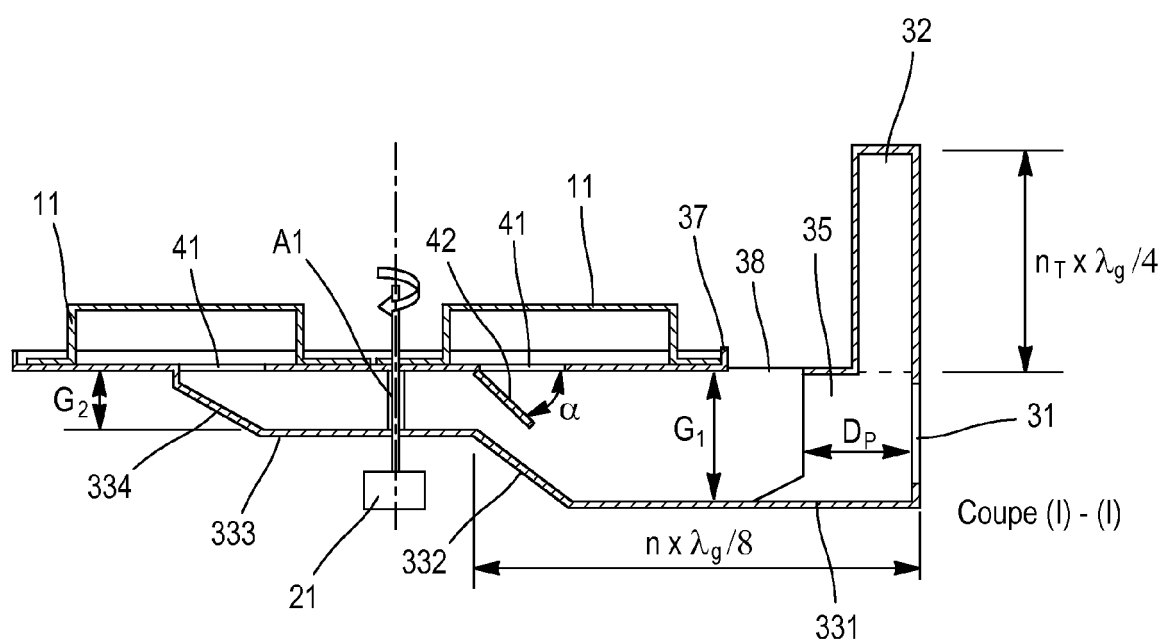


FIG. 7

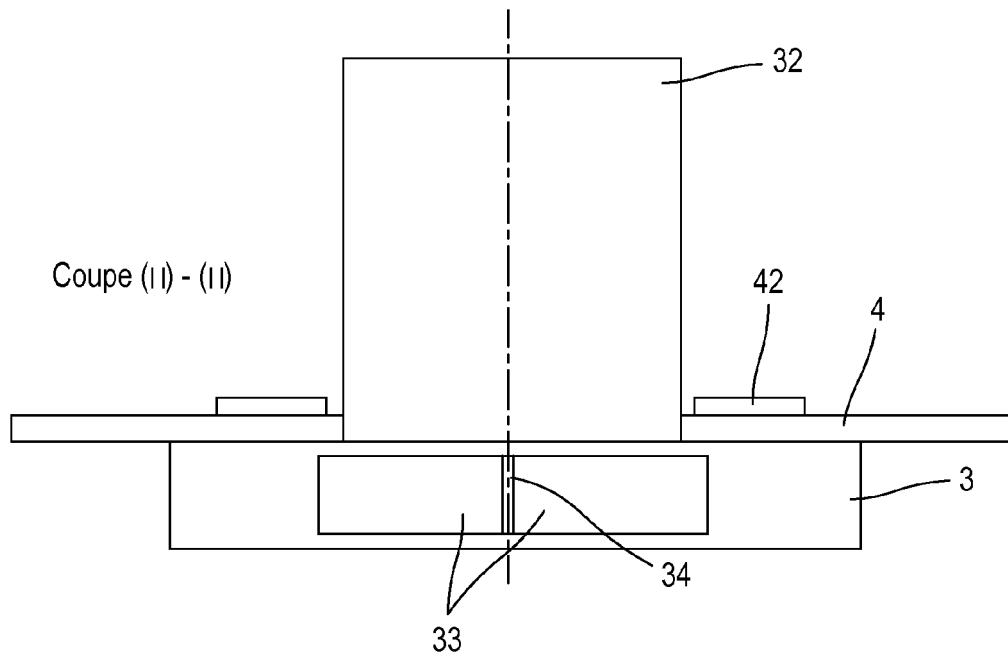


FIG. 8a

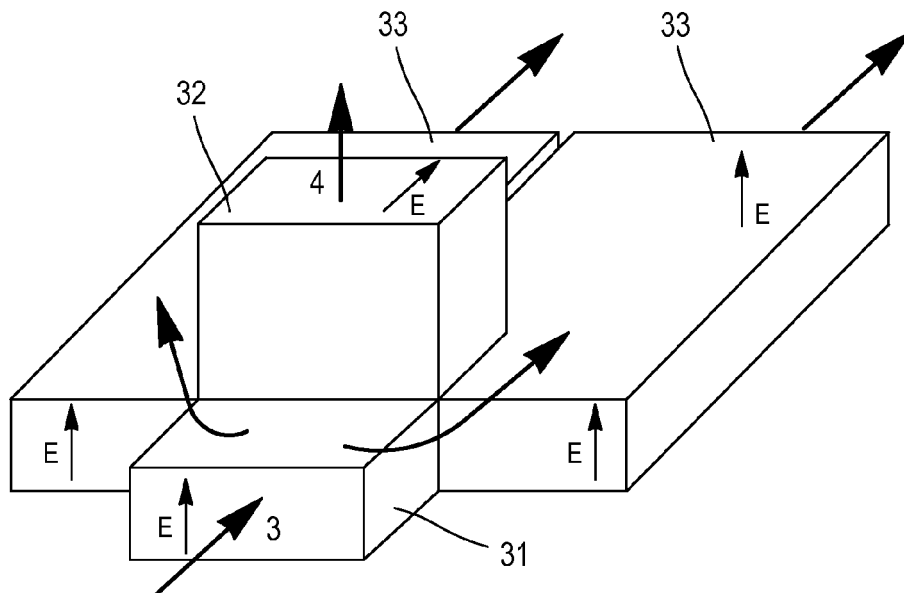


FIG. 8b

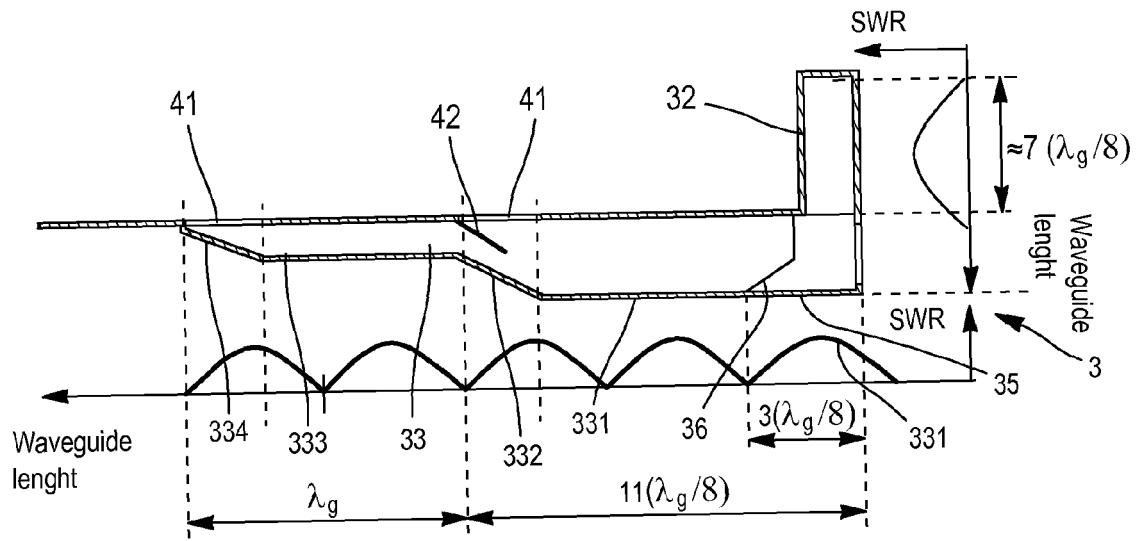


FIG. 9

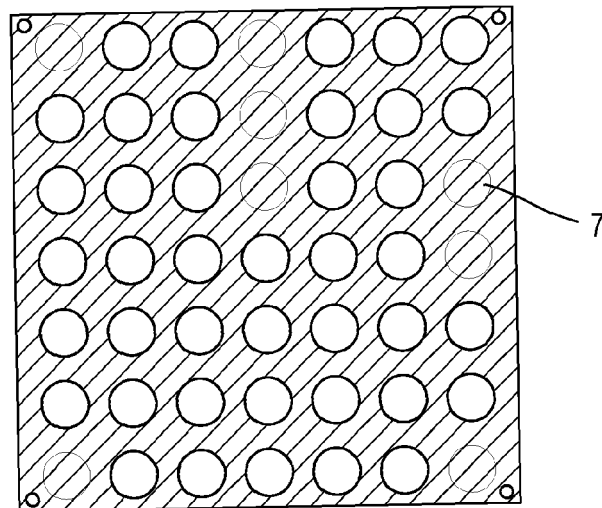


FIG. 12

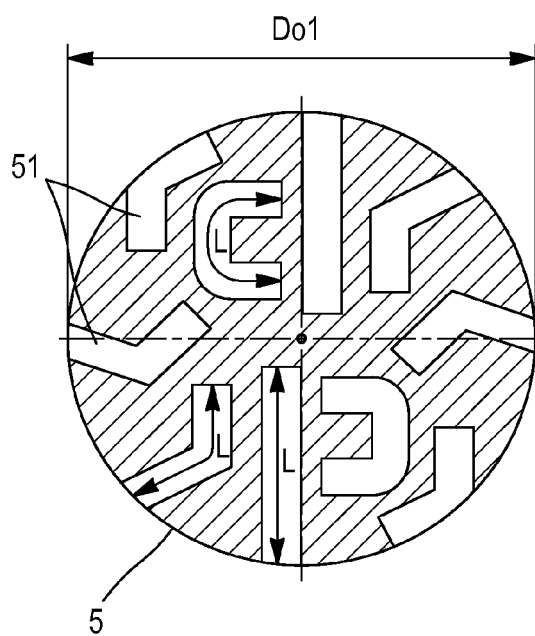


FIG. 10a

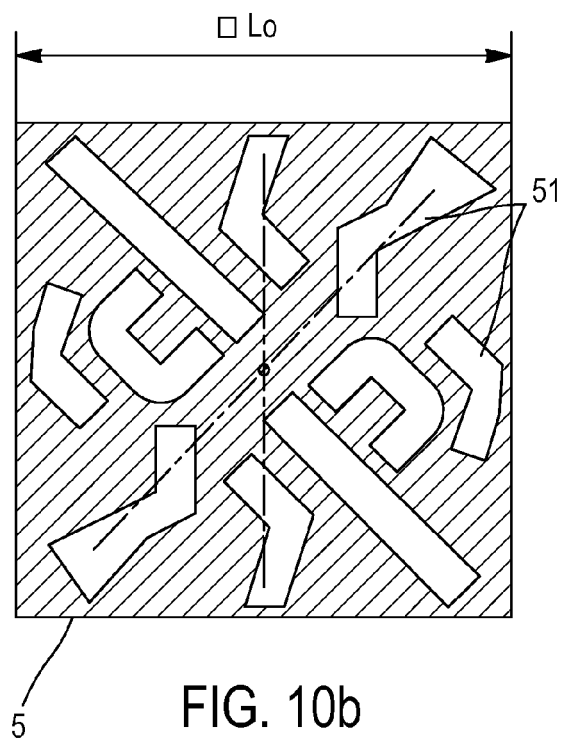


FIG. 10b

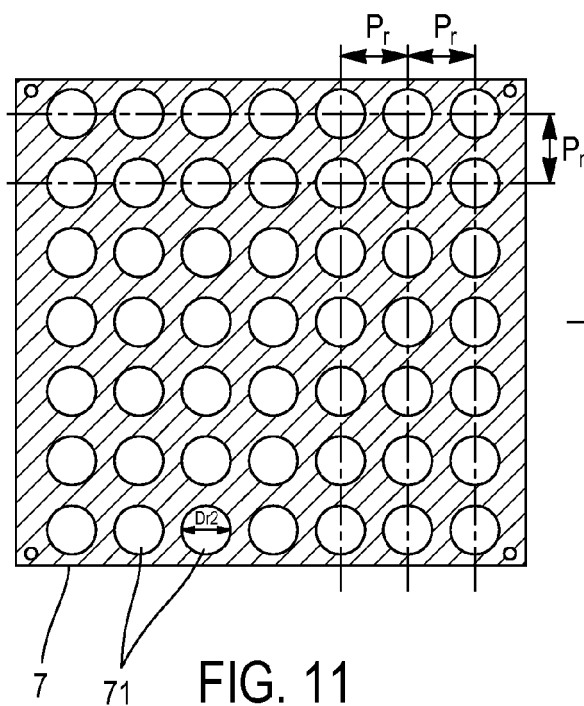


FIG. 11

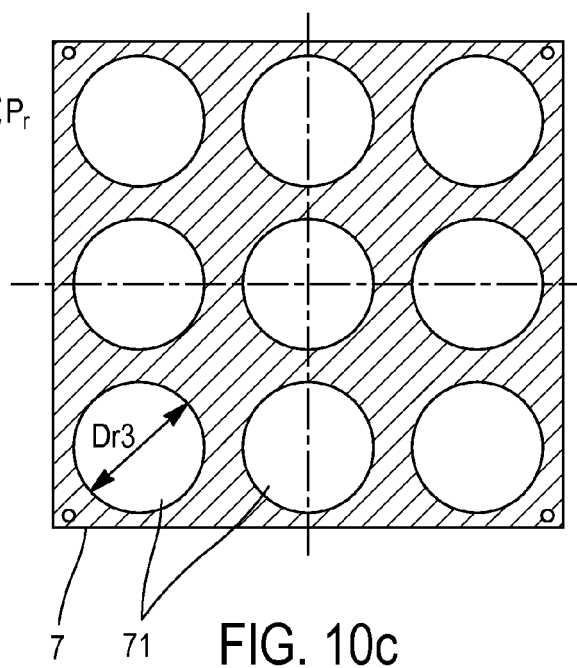
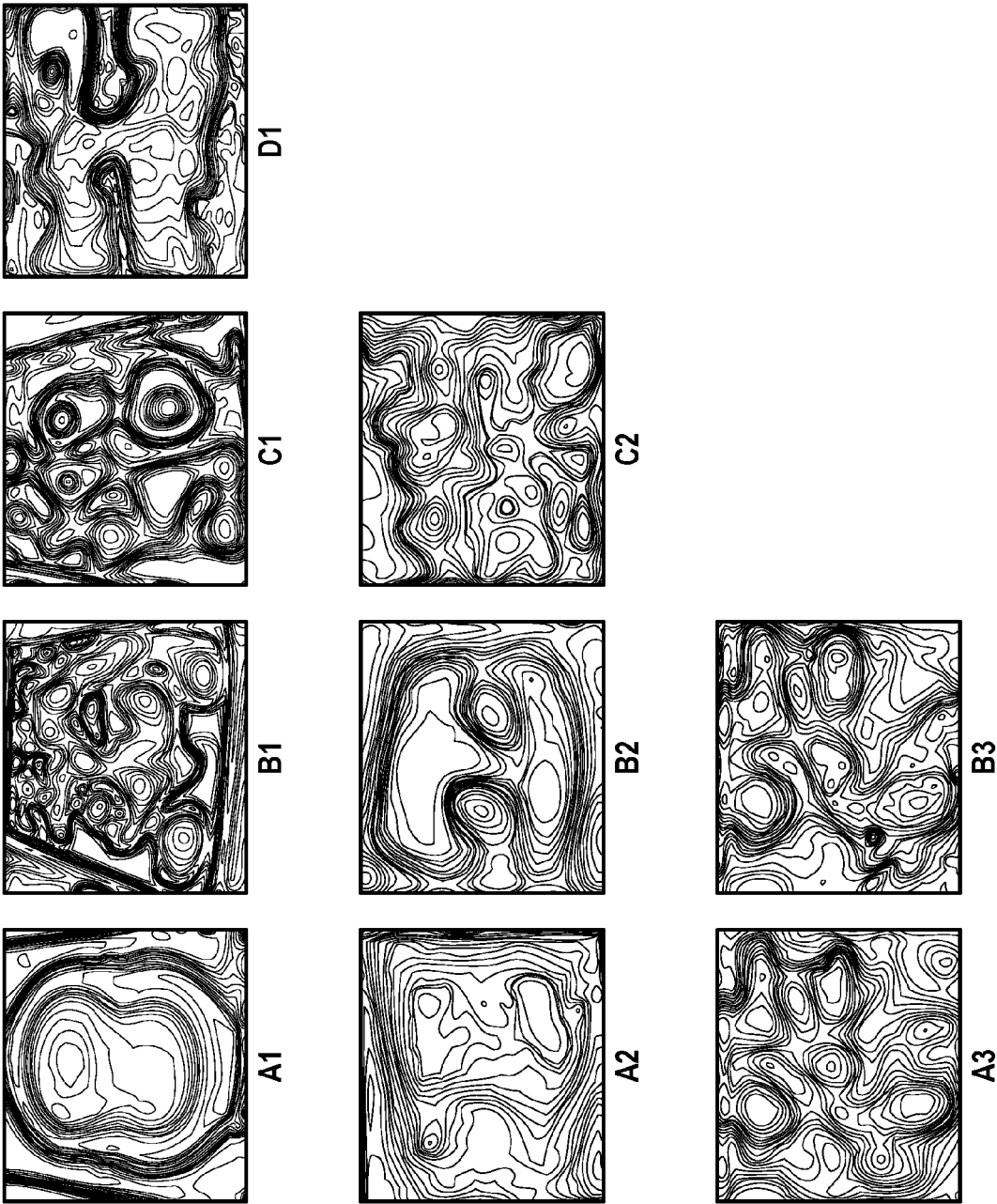


FIG. 10c

FIG. 13





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Application Number
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			H05B
The present search report has been drawn up for all claims			
Place of search Munich		Date of completion of the search 4 November 2014	Examiner Garcia Congosto, M
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