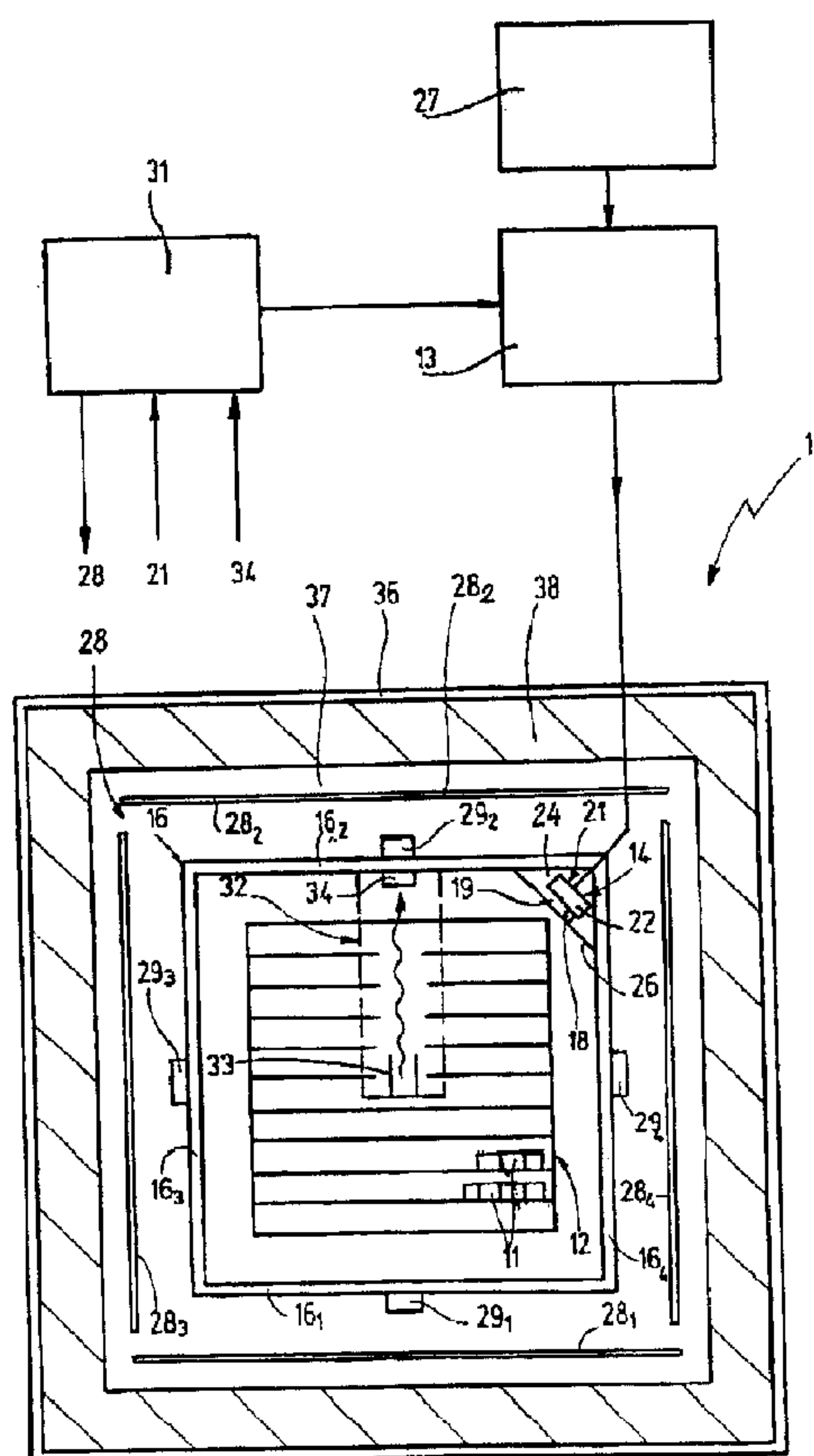




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(54) Titre : FOUR POUR LE TRAITEMENT A HAUTE TEMPERATURE DE MATERIAUX A FAIBLE FACTEUR DE PERTE DIELECTRIQUE
(54) Title: BAKING OVEN FOR THE HIGH-TEMPERATURE TREATMENT OF MATERIALS WITH A LOW DIELECTRIC LOSS FACTOR



(57) Abrégé/Abstract:

In a baking oven (10) for the high-temperature treatment of materials with a relatively low dielectric loss factor ($\tan \delta$) by heating the material by absorption of microwave energy in a resonant chamber (16), a uniform energy intensity of the microwave field is



(57) Abrégé(suite)/Abstract(continued):

to be achieved for example by irradiating the microwave energy over a broad band and/or by varying in time the frequency of the irradiated microwave energy. The resonant chamber (16) and the radiation source (13) are tuned to each other such that the relation: $(V/\lambda^3) \cdot B \geq 20$ is satisfied. V stands for the volume of the resonant chamber (16), λ for the wavelength of the microwave radiation and B its band width. V/λ^3 equals at least 300 and the clear dimensions lx, ly and lz of the resonant cavity (16) in the direction of the co-ordinates x, y and z are approximately equal to the cubic root of V. The wall (16₁ to 16₆) of the resonant cavity is made of graphite and can be heated by a heating device (28) up to the temperature of the material to be treated. The heating device is arranged outside the resonant chamber, and a heat insulating envelope (38) encloses the unit of resonant cavity (16) and heating device.



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(54) Title: BAKING OVEN FOR THE HIGH-TEMPERATURE TREATMENT OF MATERIALS WITH A LOW DIELECTRIC LOSS FACTOR

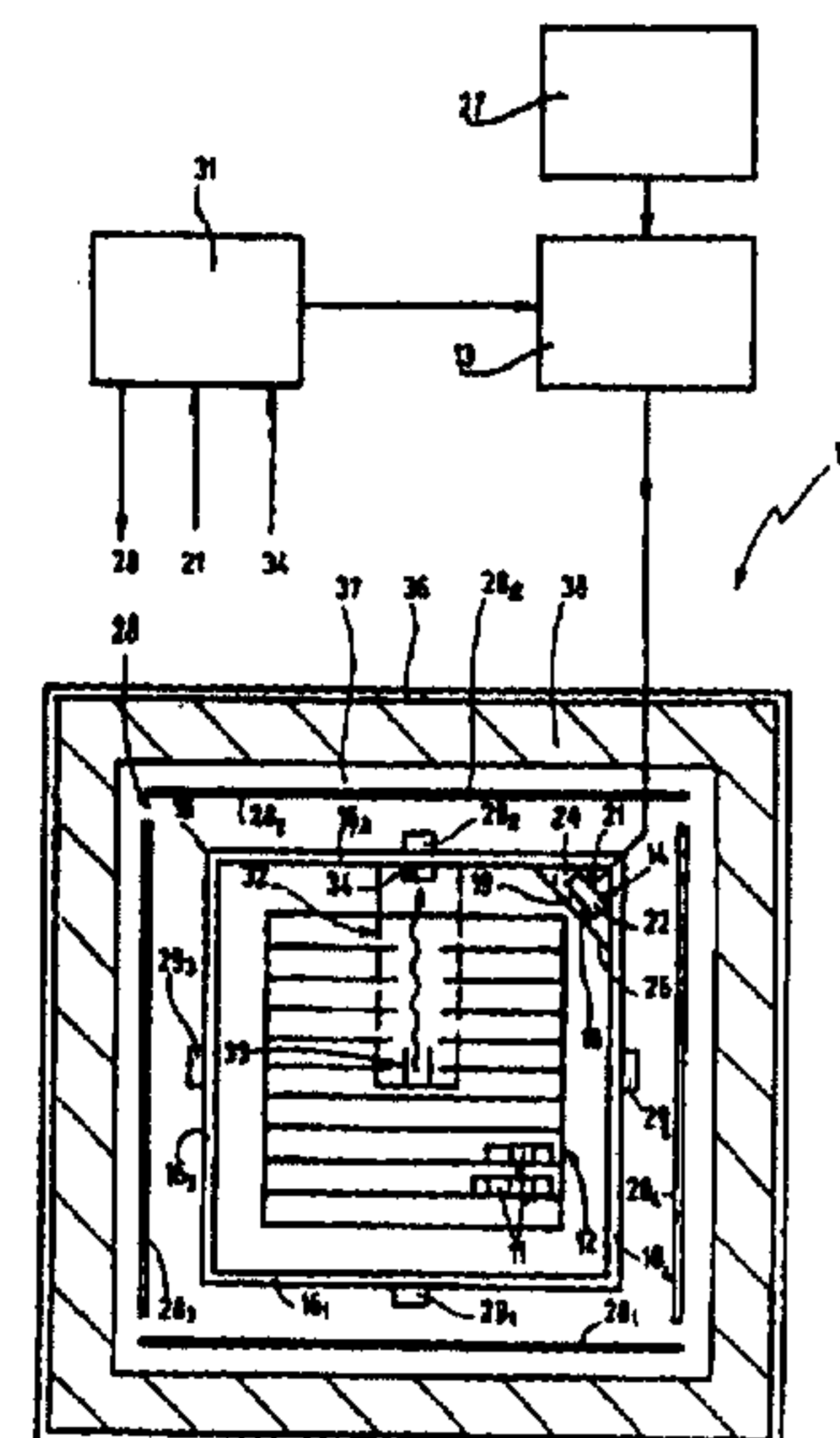
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(57) Abstract

In a baking oven (10) for the high-temperature treatment of materials with a relatively low dielectric loss factor ($\tan \delta$) by heating the material by absorption of microwave energy in a resonant chamber (16), a uniform energy intensity of the microwave field is to be achieved for example by irradiating the microwave energy over a broad band and/or by varying in time the frequency of the irradiated microwave energy. The resonant chamber (16) and the radiation source (13) are tuned to each other such that the relation: $(V/\lambda^3) \cdot B \geq 20$ is satisfied. V stands for the volume of the resonant chamber (16), λ for the wavelength of the microwave radiation and B its band width. V/λ^3 equals at least 300 and the clear dimensions l_x , l_y and l_z of the resonant cavity (16) in the direction of the co-ordinates x, y and z are approximately equal to the cubic root of V. The wall (16₁ to 16₆) of the resonant cavity is made of graphite and can be heated by a heating device (28) up to the temperature of the material to be treated. The heating device is arranged outside the resonant chamber, and a heat insulating envelope (38) encloses the unit of resonant cavity (16) and heating device.

(57) Zusammenfassung

Bei einem Brennofen (10) für die Hochtemperaturbehandlung von Materialien mit relativ niedrigem dielektrischem Verlustfaktor ($\tan \delta$) unter Erwärmung des Materials durch Absorption von Mikrowellenenergie in einem Hohlraumresonator (16), in dem, z.B. durch breitbandige Einstrahlung von Mikrowellenenergie und/oder durch zeitliche Variation der Frequenz der eingestrahlteten Mikrowellenenergie, gleichmäßige Energiedichte des Mikrowellenfeldes erzielt werden soll, sind der Hohlraumresonator (16) und die Strahlungsquelle (13) dahingehend aufeinander abgestimmt, daß die Relation: $(V/\lambda^3) \cdot B \geq 20$ erfüllt ist, worin mit V das Volumen des Hohlraumresonators (16), mit λ die Wellenlänge der Mikrowellenstrahlung und mit B deren Bandbreite bezeichnet sind, des weiteren die Größe V/λ^3 einen Wert von mindestens 300 hat und die lichten Abmessungen l_x , l_y und l_z des Hohlraumresonators (16) in den Koordinatenrichtungen x, y und z jeweils einen Wert um $\sqrt[3]{V}$ haben. Die Resonatorwand (16₁ bis 16₆) besteht aus Graphit. Sie ist mittels einer Heizeinrichtung (28) auf die Temperatur der Behandlungsgutes aufheizbar. Die Heizeinrichtung ist außerhalb des Hohlraumresonators angeordnet, und ein Wärmedämmmantel (38) umschließt die den Hohlraumresonator (16) und die Heizeinrichtung umfassende Baugruppe.



**BAKING OVEN FOR THE HIGH-TEMPERATURE TREATMENT OF MATERIALS WITH
A LOW DIELECTRIC LOSS FACTOR**

Description

5

The invention concerns a baking oven for the high-temperature treatment of materials with a relatively low dielectric loss factor, wherein the materials are heated by absorption of microwave energy in a resonant chamber, and with further
10 features characteristic in this art as set forth in the precharacterizing portion of claim 1.

A baking oven of this type is known from WO95/05058 PCT/GB94/01730.

15

This known baking oven has a design that is suitable for sintering ceramic materials which rest in a pile or heap within a cuboidal resonant chamber during sintering, within which chamber an again somewhat cuboidal space for the pile is
20 bordered by a cuboid shaped heat insulator arrangement, which corresponds to the area or space within the resonator, within which it is presumed that a sufficiently homogeneous distribution of the electric field strength occurs. The uniformity of the electric field strength or, as the case may
25 be, the cubic shape thereof is a precondition therefor, that the sinterable material is sufficiently "uniformly" thermally treatable. In order to be able to counter the effect, that with increasing warming of the sinterable material the radiation of heat from the edge areas of the sinter pile leads thereto, that
30 on the inside of the pile a higher temperature exists than in the mentioned edge areas, an effect which is characteristic for microwave baking ovens, a device is provided, which makes it

possible to conventionally warm the edge areas of the pile being sintered, that is, supplementation by means of a resistance heater, in order in this manner to achieve an equalization of the temperature profile within the pile of material being
5 sintered.

The known baking oven may be suitable for producing approximately homogeneous thermal conditions in the overall volume of material being processed, however in the case of
10 relatively small processing volumes it is associated with the disadvantage that the thermal insulator arrangement, which is subjected to the microwave radiation, absorbs a major portion of the introduced microwave energy, which necessarily leads to a high consumption of microwave energy, which is not available for
15 the desired thermal treatment of the material being sintered. This can be seen from the fact that, in practice, the total volume of the insulator material is significantly larger than the volume of the material being sintered. The known baking oven is thus not suitable as an industrially useful oven, since
20 there is no efficient utilization of the microwave energy, of which the cost of production is however much higher than in the case of "conventional" heating by means of an electrical resistance heater.

25 While a baking oven designed as a continuous heating or pusher-type furnace may be known from WO95/05058, which is designed as a tunnel oven with heating zones of various temperatures, through which the material being sintered is transported over transport rolls, wherein the supplemental heating means is
30 arranged or provided outside of the treatment chamber and in which the thermal insulation, which insulates the surroundings

against the high-temperature zone, surrounds the oven from the outside. In the case of this oven however the arrangement necessarily results in insufficient field homogeneity, that is, this oven design is only useful because relatively small objects
5 are sintered serially and since there is a continuous movement through the non-homogeneous areas, thus there is no requirement for a homogeneous field distribution.

The known tunnel oven may be suitable for materials with high
10 dielectric loss, which strongly absorb microwave energy, but it is however not suitable for treatment or processing of materials to be sintered with relatively weak dielectric losses, which can be processed practically only in significant numbers of pieces in a resonant chamber with high field homogeneity.

15

The known tubular oven would not be suitable for materials with low dielectric loss factor, which technically however are also of high interest.

20 It is thus the task of the invention, to provide a baking oven of the above described type, which enables a high-temperature treatment of low dielectric loss factor sinterable materials with in a large processing volumes, which on the basis of its dimensions can be employed as an industrial oven and thereby at
25 the same time is operable with a high degree of efficiency of energy utilization. Further, the baking oven should be suitable for utilization within a wide temperature range up to 1800°C.

This task is inventively solved by the characterizing features
30 of patent claim 1.

The desired functional characteristics and advantages of the inventive baking oven are at least the following:

By adhering to the dimensional relationships according to characteristic a) there results with respect to the outer dimensions of the resonator a suitable homogeneity of the field distribution for a large processing volume, within which a large number of evenly distributed or loaded sinterable objects can be treated.

10

By the positioning of the insulator material towards the outside it is ensured, that the major portion of the produced microwave radiation can be used for the respective given processing requirements. Thereby an economical operation of the inventive oven as an industrial oven is made possible.

15

By the employment or utilization of graphite as the wall or lining material for the resonant chamber it is not only possible to drastically increase the temperature range within which the high-temperature processing of sinterable material is possible, but rather it is also, in comparison to the conventional resonant chamber constructed of steel, to reduce the weight thereof and therewith the wattage or heat generation energy requirement of the supplemental electric heater device, which is necessary for the establishment of the desired temperature profile. This also contributes to the economic efficiency of the operation of the inventive baking oven when designed as an industrial oven.

20

25

In the preferred design of the baking oven, there is employed as microwave radiation source at least a magnetron, which is

30

tunable about a center frequency within a band width B, which is characterized by the equation $B = \Delta f/f$, in which the frequency deviation is indicated by Δf , of a approximately 1/100.

- 5 Such a magnetron can have a center frequency of, for example, 2.45 GHz, which corresponds to a tuning range of from 2.438 GHz to 2.462 GHz.

10 Thereby a large number of modes of oscillation can be excited or stimulated in the resonant chamber, which, by tuning the magnetron between the border frequencies, can be stimulated or induced at intervals sequentially one after the other.

15 The advantageous result thereof is that at various times various spatial distributions of the field strength occur, which taken over time produce a substantially homogeneous field in the processing area.

20 In a useful embodiment the radiation source is so constructed, that the time for the frequency modulation between the border frequencies lies in a range of tenths of a second, that is between 0.05 and 1 second, that is, within a time span, which is small in comparison to the thermal relaxation time of the material being sintered.

25

This step is advantageous, in order to avoid thermal tensions within the material being sintered. This type of tension can build up when, as a consequence of too-small a rate-of-change the frequency distribution which is characteristic of a particular frequency, and which is necessarily non-homogeneous, is maintained for too long a period of time.

In the sense of an effective broadening of the frequency band, within which the resonant chamber is excitable, it can also be of advantage, when a number n of magnetrons are provided as
5 microwave radiation sources, which are operable at various center frequencies f_i ($i = 1$ through n) and are tunable within their respective band widths Δf_i .

A quasi-continuous "seamless" tuning range of the frequency
10 results, when the frequency separation of the center frequencies of the magnetrons which are next to each other in the frequency scale satisfy the equation $(\Delta f_i + \Delta f_{i+1})/2$.

In the preferred embodiment of the baking oven the resonant
15 chamber has a cuboidal design, preferably such that the edge lengths l_x , l_y and l_z of the resonant chamber boundary correspond at least to the 10-fold of the wavelength λ of the microwave radiation.

20 Alternatively thereto the resonator chamber can, as provided in claim 7, when viewed in the direction in which the planar boundary walls of the resonator chamber intersect each other along parallel corner edges, have a polygonal shape, that is the shape of a prismatic chamber profile. In this design the
25 resonator can be assembled in a simple manner of plate-shaped elements, particularly also, as set forth in claim 8, of plate-shaped graphite material.

This design of the resonator chamber has the advantage, that the
30 baking oven can be operated at very high temperatures, so that

sinter processes are possible in the temperature range of up to 1800°C.

5 In the case of a multi-sided polygonality and, in certain cases, regular polygonal design of the resonator chamber it is also possible to approach with good approximation a cylindrical tubular-shaped resonator.

10 This design has the advantage, when viewed from the perspective of construction, that the constructed shape of the resonator can better approximate the shape of a conventionally cylindrical outer container, which can be evacuated and/or be flooded or flushed with inert gas.

15 In order to introduce the high microwave power necessary for sintering the sinterable material with a homogeneous spatial distribution in the resonator chamber, it is advantageous to select an antenna arrangement, which in accordance with claim 9 has an omni-directional radiation characteristic, that is,
20 avoids a specific direction of radiation. An antenna of this type is designed, in accordance with the characteristics set forth in claim 10, as a group emitter comprising multiple individual emitters, of which the individual emitters can be supplied in a statically distributed phase position.

25

Such a group emitter is designed, in a preferred embodiment of the oven, as a slit emitter in accordance with claim 11, which includes a plurality of radiation slits with a slit length of between $\lambda/4$ and $\lambda/2$ and, in comparison thereto, a small slit
30 width w , which viewed in the direction of radiation of the microwave field in the source wave guide, are distributed over

the length thereof in such a manner, that per slit the same or approximately similar amounts of microwave energy can be introduced into the resonant chamber, whereby, viewed in the direction of radiation of the microwave field in the wave guide, the extension of the individual slits corresponds to between w and $\lambda/2$, of which further in the direction of radiation of the microwave field in the wave guide measured distance sequential slits of the slit antenna have a value of between $\lambda/2$ and $3\lambda/4$ and, with respect to the center plane of the wave guide, running in the direction of radiation, the sideways separation of the slits from this center plane, over the length of the wave guide, increases stepwise, and the statistic distribution of the longitudinal slits, which form the individual radiation elements, is provided with reference to the longitudinal center plane of the wave guide.

In this design of the slit antenna, a very good omni-directional radiation characteristic is achieved already when at least 20 individual slits are provided, wherein with increasing number of slits an always more effective approximation of the antenna characteristic of an omni-directional characteristic is achieved.

In the special design of the slit emitter as described in accordance with claim 13, at least some of its slits can run perpendicular to the direction of propagation or expansion of the microwave field in the wave guide.

In consideration of an even energy introduction in the resonant chamber, it can also be of advantage when multiple group emitters of the above described type are provided, as a result

of which a statistically more even distribution of the phase positions of the microwave energy introduced over the individual antenna elements can be achieved and on the other hand also a correspondingly increased energy input is possible, which is
5 appropriate for the heating of a large-volumed pile of sinterable material.

Both for construction reasons as well as reasons of radiation characteristics ("horn"-effect of the resonator walls) it can be
10 particularly advantageous, when the antenna(s) are provided in strip-shaped edge areas of planar parts of the resonator wall, which run immediately adjacent to corners of the resonator walls along which the resonator inner surfaces join with each other.

15 The supplemental heater, which surrounds the resonator and/or the wave guides, via which the antenna(s) are supplied, is designed as an electrically controllable resistance heater, which is controlled in accordance with a preprogrammed temperature profile, which is designed to correspond to the
20 temperature sequence in the material being sintered, which for its part is monitored by a temperature sensor, preferably a pyrometer, and is utilized for comparing the actual and intended values for the heating of the resonator wall, of which the temperature is compared with the temperature of the material
25 being sintered in the sense of a follow-up control, which is essentially controlled or determined by the microwave power radiated in.

Herein it is advantageous, that temperature sensors are provided
30 for various wall areas of the resonator, by means of which the, in certain cases, varying resonator wall temperatures, can be

sensed, and that the heating of the individually monitored wall areas involves associated heating elements, which for their part are individually controllable, wherein it is advantageous in the case of a cuboid-shaped resonator to provide for each resonator wall an individual heater element and an individual temperature sensor.

In the positioning of the thermal insulator outside of the resonator chamber and also outside of the heating element in accordance with the invention, the insulator material itself can be formed of a material based on graphite, for example graphite felt, which then prevents, presuming it is positioned on the inside of the housing surrounding the resonator, on the basis of the conductivity of the graphite material, an effective suppression of any microwave radiation emission towards the outside.

Further details of the inventive baking oven can be seen from the following description of a special embodiment of the invention and possible variations of the same on the basis of the drawings. There are shown in

Fig. 1 an illustrative embodiment of an inventive baking oven for the high-temperature processing of sinterable ceramic materials with low dielectric loss factor, which are heatable within the cuboidal shaped resonant chamber of the baking oven by absorption of microwave energy, in schematically simplified diagrammatic representation,

30

Fig. 1a a simplified diagrammatic perspective view of the resonator chamber and the arrangement of the processing tolerances;

5 Fig. 2 details of a slit antenna device for introduction of microwave energy into the resonator chamber of the baking oven according Fig. 1, in schematic simplified, partially broken-away perspective representation and

10 Fig. 2a the slit antenna according to Fig. 2 in simplified top view.

The baking oven indicated overall with 10 in Fig. 1 is intended for the thermal processing, in particular sintering, of
15 essentially schematically represented work pieces 11, which achieve material characteristics required in finished work pieces for predetermined applications and/or spatial dimensions only as a consequence of this thermal processing.

20 Typical work pieces 11, which are produced on the basis of nitride-ceramic material, in particular Si_3N_4 , such as ball-bearing housings, valve bodies and housings, and nozzles, or which can be produced on the basis of ceramic oxide materials, for example, sealing discs and rings, and which require a
25 sintering processing, can be exposed to this thermal treatment in the baking oven 10.

These are materials with a relatively low dielectric loss factor ($\tan \delta < 0.01$), which are arranged in a pile indicated overall
30 with reference number 12.

The heating of the sinterable material comprised of work pieces 11 as achieved by absorption of microwave energy, which is produced by a microwave source 13 and is fed via an antenna-arrangement generally indicated with 14 with omni-directional radiation characteristics in the inside of a resonant chamber indicated with 16 with electrically conductive walls 16₁ through 16₆, which in the shown special embodiment has the form of a cube, of which the dimensions l_x , l_y and l_z are significantly larger, that is approximately 10 times larger, than the wavelength λ of the microwaves produced by the microwave source 13, and respectively lies in the size range of

$$\sqrt[3]{V}$$

wherein V_{res} represents the volume of the resonant chamber ($V_{res} = l_x \cdot l_y \cdot l_z$). The processing space, within which the not individually represented sinterable material is maintained in a pile as dielectric load of the resonant chamber 16, is schematically represented in Fig. 1a as a central partial space 17 geometrically similar to the internal space of the resonant chamber 16, of which the useful volume for thermal treatment of the sinterable material 11 can correspond to approximately 1/3 of the resonator volume V_{res} .

In such a resonator 16 the resonance conditions for the wavelength of the microwave radiation, which is resonant in the resonator 16, would be as follows

(1)

$$\lambda_r = \frac{2}{\sqrt{\left(\frac{m}{Lx}\right)^2 + \left(\frac{n}{Ly}\right)^2 + \left(\frac{o}{Lz}\right)^2}}$$

wherein m, n and o represent quantum whole values, with which the equation (1) can be satisfied.

5

The resonant modes which can be stimulated in such a resonator chamber produce a field distribution within the resonator chamber which periodically varies over the three coordinate directions x, y and z, wherein the square (E^2) of the dielectric field strength (E) of the electric field produced in the resonator chamber varies between 0 and the maximum amount, that is, a field distribution, which is spatially extremely non-homogeneous.

15 The homogeneous distribution of the electric field energy necessary for a qualitatively even treatment of sinterable material distributed over the processing partial space 17 can be achieved in good approximation, when the resonator chamber is stimulated or energized by a high number of resonant oscillation
20 modes and these oscillation modes are at least temporarily superimposable or heterodyned, wherein the number ΔN of the oscillation modes which can be stimulated are determined by the equation

25

(2)

$$\Delta N = \frac{8 \cdot \pi \cdot V_{res}}{\lambda^3} \cdot \frac{1}{Q_{total}}$$

in which V_{res} represents the volume of the resonator chamber, λ
 5 represents the vacuum wavelength and Q_{total} represents the total Q
 value or quality of the previously described device 10, 11, 12,
 13, 14, which for their part are characterized by the equation

(3)

$$\frac{1}{Q_{total}} = \frac{1}{Q_{res}} + \frac{1}{Q_{ant}} + \frac{1}{Q_{diel}} + \frac{1}{Q_{source}}$$

10

In this respect the quality or Q factor of the resonator is
 15 represented by Q_{res} , which is determined by the equation

(4)

$$Q_{res} = \frac{3 \cdot V_{res}}{2 \cdot A_{res} \cdot e}$$

20

Q_{ant} represents the power of the antenna-arrangement, for which
 the following equation applies

(5)

$$Q_{ant} = \frac{8 \cdot \pi \cdot V_{res}}{A_{ant} \cdot \lambda}$$

25

Q_{diel} represents the power of the sinterable dielectric material,
for which the following equation applies

5

(6)

$$Q_{diel} = \frac{V_{res}}{V_{diel}} \cdot \frac{1}{\sqrt{\epsilon_r} \cdot \tan \delta}$$

and Q_{source} represents the power of the microwave source (13),
10 which is determined by the equation

(7)

$$Q_{source} = 1/B$$

15

In the equations (4), (5), (6) and (7) the symbols have the
following meanings

20 A_{res} the total surface area of the resonator wall,

e the penetration depth in the resonator wall

A_{ant} the emission surfaces of the antenna-arrangement 14,

25

V_{diel} the volume of the dielectric material to be processed
11,

ϵ_r the dielectric number of the sinterable material 11,

$\tan \delta$ the dielectric loss factor of the sinterable material
5 and

B the band breadth of the microwave source 13.

In the baking oven 10 selected for illustration a magnetron with
10 a base frequency of 2.45 GHz is provided as microwave emitter
source 13. The resonator volume V_{res} is 1.4 m^3 , so that the
relationship V_{res}/λ^3 has a value of 770. A value of 7.6 m^3 is
assumed for the value A_{res} for the total surface area of the
resonator walls 16₁ through 16₆. The resonator walls 16₁ through
15 16₆ are comprised of a plate-shaped graphite material, so that
with the given frequency of the microwave source a penetration
depth e of $32 \text{ } \mu\text{m}$ results, which corresponds to a power or quality
of the resonator wall of approximately 8600.

20 For the "emitting" antenna surface area a value A_{ant} of 60 cm^2 is
presumed, which corresponds to a power Q_{ant} of the antenna-
arrangement of 48000. For the volume of approximately 0.03 m^3
occupied by the sinterable material 11 there results a value of
the power Q_{diel} of the sinterable material of 2100, when for the
25 dielectric coefficient thereof a value of 8 and a loss factor of
0.008 is selected. In the operation of the magnetron 13 with a
fixed frequency the band breadth B of the microwave radiation or
emission produced by the magnetron is smaller than 10^{-6} , which
corresponds to a source power Q_{source} of more than 10^6 . In the
30 dielectric treatment of the resonator chamber with the given

circumference or volume, the total power Q_{tot} corresponds approximately to the power Q_{diel} of the dielectric material, and the number of the oscillation modes ΔN capable of stimulation has a value of approximately 9. Therefrom it can be seen that a
 5 sufficient number of oscillation modes which are necessary for a sufficiently even distribution of the electric field in the resonator chamber can only be achieved by a broad band microwave source.

10 In accordance therewith the baking oven 10 is so arranged, that the following equation applies

(8)

$$V_{res} \cdot B / \lambda_3 \geq 20$$

15

The antenna device 14, by means of which the microwave energy produced by the magnetron 13 is fed into the resonator chamber 16, is formed as slit emitter, which includes a number emission
 20 slits 18, of which each forms an antenna element, of which each emitting antenna surface corresponds to the unobstructed slit surface. These emitter slits 18 are provided on a longitudinal wall 19 of a rectangular wave guide 21 which simultaneously also forms an inner wall area of the resonator chamber (Fig. 2), in
 25 which the microwave energy produced by the magnetron 13, introduced into one end of the wave guide 21 is only in the condition in the TE_{10} -mode (fundamental harmonic oscillation) in the shown arrangement-example to radiate in the c-direction in such a manner that the electric field vector runs perpendicular to the wave guide longitudinal wall 19 provided with the slits

18 and the field of distribution of the electric field in the internal space of the rectangular wave guide runs essentially symmetrical to the longitudinal center plane 23 thereof, which extends internally in the direction of propagation of the microwave field in the wave guide 21. These emission slits 18 are provided distributed over the length l_c of the rectangular wave guide 21 in such a manner that per emission slit 18 respectively identical or approximately identical amounts of microwave energy are emitted into the resonator chamber 16, and that the phase positions of the electromagnetic fields introduced into the resonator chamber 16 by the emissions slits are varied in a statistical sequence.

Seen in the direction of propagation of the microwave field in the wave guide 21, the separation d of the sequential slits of the slit antenna 14 correspond to between $\lambda/2$ and $3\lambda/4$ (Fig. 2a), wherein departing from the embodiment selected for illustration, in which the longer slit edges run parallel to the longitudinal central plane 23 of the wave guide 22, slit configurations are possible wherein slits are running with longitudinal edges diagonally thereto. In the shown configurations of the slit antenna 14, in which the emission slits run parallel to the longitudinal plane 23, the length l of the individual slits 18 is $\lambda/4$ and $\lambda/2$ and is significantly larger than the width w of the slit measured perpendicular to the longitudinal center plane 23 or as the case may be the direction of propagation of the microwave energy in the rectangular wave guide. Measured over the length of the rectangular wave guide 21, of which microwave energy produced by the magnetron 13 is introduced at one end, the sideways separation a of the emitter slits from the

longitudinal center plane 23 of the rectangular wave guide 21 increase stepwise.

The sequential arrangement of the emission slits 18' and 18'' provided respectively on one of the sides of the longitudinal central plane (Fig 2a) correspond in the separation grid of the slit separations d , seen in the direction of propagation of the microwave field in the rectangular wave guide 21, to a "binary" random pattern of slit pairs (1,0) and (0,1), wherein (1,0) means that the slit 18' is provided in one side, the "left" side, of the longitudinal central plane 23 of the rectangular wave guide 21, however not a symmetrically thereto arranged slit 18'' and the combination (0,1) means that on the other "right" side of the longitudinal central plane 23 a radiation emission slit 18'' is provided, however not on the oppositely lying, "left" side. The combination (1,1), which would correspond to a phase difference of the precisely oppositely lying positioned emission radiation slits 18' and 18'' radiated field of $\pi/2$, as well as the combination (0,0) are excluded from the illustrated embodiment for explanatory purposes, without limitation in practice. The slit antenna which is constructed in principle as described above works as a group emitter, of which the individual emitters formed by slits 18 or as the case may be 18' and 18'' are fed with statistical varying phase position, whereby the emission characteristic of the antenna-arrangement 14 is in very good approximation to an omni-directional characteristic.

The rectangular wave guide 21 provided for supplying emission slits 18 of the antenna-arrangement 14 is, according to the schematic representation of Fig. 1, integrated in a prismatic

graphite body 24, of which the outer cross-sectional contour corresponds to that of an equilateral right-angled triangle, through the hypotenuse 26 of which in the representation in Fig. 1 a resonator chamber limiting surface is represented, which in one corner area of the resonant chamber 16 communicates between the resonator walls 16₂ and 16₄ which connect with each other at right angles in the area of the antenna-arrangement 14, whereby the wave guide surfaces which border the wave guide internal space 22 run pairwise parallel or, as the case may be, perpendicular to the diagonal inner longitudinally bordering surface 26 of the resonator chamber 16, which is formed by the "hypotenuse" surface of the graphite body 24.

For increasing the number of modes of oscillation excitable within the resonator chamber, which benefits the evenness of the field distribution in the resonator chamber, to reduce "effective" quality Q_{source} of the magnetron provided as an energy source a design of the magnetron 13 is provided, in which this modulation frequency is variable within a band breadth of 1/100 of the base frequency f of 2.45 GHz. The cycle time of the frequency variation, which is controllable by means of an electronic control unit 27, is determined by the thermal relaxation relationship of the sinterable material 11 in so far that it is small in comparison to the thermal relaxation time of the respective sinter material to be processed. In accordance therewith the electronic control unit 27 is so designed that the cycle time can amount to between 0.05 and one second.

For the purpose of a - temporal - reduction of the source power Q_{source} there can also be employed the measure that multiple magnetrons are provided as microwave radiation source, which are

not shown individually, which are operable at differing base frequencies f_i ($i = 1...n$) and respectively have characteristic band widths B_i , when it then useful, when the frequency separations Δf_i of the magnetron modulation frequencies which are adjacent to each other in the frequency scale at least satisfy the value

$$\frac{\Delta f_i + \Delta f_{i+1}}{2}$$

When two or more antenna-arrangements 14 are provided for introduction of microwaves energy into the resonator chamber 16, it is useful, when these are azimuthally grouped approximately equidistant about a "central" axis parallel to the polygonal edge of the resonator chamber in order to achieve an even introduction of microwave energy into the processing or treatment chamber 17 of the resonator chamber.

The baking oven 10 is provided with a heating device generally indicated with 28, which includes six electric resistance heating elements 28₁ to 28₆ corresponding to the number of the large surface wall elements 16₁ through 16₆ of the resonator chamber 16, of which the heating capacities are individually controllable, so that the temperature of the wall elements 16₁ through 16₆ can be individually influenced. The wall elements 16₁ through 16₆ are respectively provided with at least one temperature sensor 29₁ through 29₆, which produce the characteristic electric output signal for the actual value of the wall temperature.

Further there is provided a pyrometer indicated generally with 32, by means of which the temperature of the sinterable material 16 can be measured. This pyrometer 32 includes a sensor or probe body 33 provided in a suitable position in the pile or heap 12 and an electro-optic sensor 34, by means of which the emission temperature of the probe body 33 can be detected, so that a herefor characteristic electric output signal of the sensor 34 is a precise measurement for the temperature of the material being sintered. The electronic control unit 31 of the heating device 28 transmits a compared processed signal of the actual value-output signal of the pyrometer-device 32 as well as the temperature sensors 29₁ through 29₆ and transmits also a control signal for the heating elements 28₁ through 28₆ as well as the power control signal for the microwave source 13 in the sense that the wall temperature of the resonator chamber 16 overall corresponds precisely as possible to the temperature of the sinterable material 16. The sequential progress of the oven temperature, that is, both the temperature of the material being sintered as well also the resonator wall temperature(s), is controlled according to a program, which provides a qualitatively good treatment result taking into consideration the characteristics of the material and the geometric dimensions of the work pieces 11.

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The resonator chamber 16 and the heating elements 28₁ through 28₆ of the heating element 28 provided for heating the walls 16₁ through 16₆ thereof are provided within a stable steel housing 36, which is constructed to be air-tight for the purpose of the possibility of an inert gas dousing of its internal space 17 inclusive of the resonator-chamber, or an evacuation of the

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same. The steel housing 36 is covered on the inner side of the baking oven 10 with a thermal insulation layer 36 for the thermal insulation of its internal space against the environment, which is comprised of a high-temperature resistant
5 insulation material, for example graphite felt.

Patent Claims

1. Baking oven for the high-temperature treatment of materials with relatively low dielectric loss factor ($\tan \delta$) by heating the material by absorption of microwave energy in a resonant chamber, in which the material to be treated is arranged within a central area of the resonator, wherein a uniform energy density of the microwave field is achieved, for example, by irradiating with broadband microwave energy and/or by varying the frequency of the irradiated microwave energy over time, so that in each volume element of the treatment area the square of the electric field strength of the microwave field has the same value, at least over time, within a minor tolerance, wherein an electric heating device is provided, with which the resonator wall can be heated to the same temperature as within the material to be treated, for example, in the sense of a servo control the temperature of the material to be treated can be followed, and wherein a heat insulating envelope is provided, which insulates the baking oven against heat loss into the environment, characterized by the following features:
 - a) the resonator chamber (16) and the radiation source (13) are sufficiently attuned to each other, so that the relation

$$\frac{V}{\lambda^3} \cdot B \geq 20$$

is satisfied, wherein V is the volume of the resonator chamber (16), λ is the wavelength of the microwave radiation and B is their band width, further the amount V/λ^3 has a value of at least 300 and the transparent dimensions l_x , l_y and l_z of the resonator chamber (16) in the coordinate directions x , y and z have a value of

$$\sqrt[3]{V}$$

each;

- b) the heating device (28) is arranged outside of the resonator chamber (16) in the immediate vicinity of the resonator wall, and the heat insulating envelope (38) is arranged so that it encompasses the resonator chamber (16) and the heating device (28) from the outside,
 - c) the resonator wall (16_1 through 16_6) consists of graphite or equivalent temperature maintaining and electrically conductive material.
2. Baking oven according to claim 1, thereby characterized, that as microwave radiation source (13) a magnetron is

provided, which is tunable about a basic frequency f within a band width $B = \Delta f/f$ of preferably $1/100$.

3. Baking oven according to claim 1 or claim 2, thereby characterized, that time intervals in which within a continuous or stepwise variation of the oscillation frequency of the microwave radiation source (13) occurs, lies between 0.05 and 1s, preferably around 100ms.
4. Baking oven according to one of claims 1 through 3, thereby characterized, that an amount n of magnetrons are provided, which are operable at various central frequencies f_i ($i = 1$ through n) and each have characteristic band widths B_i .
5. Baking oven according to claim 4, thereby characterized, that the frequency separations of the center frequencies of the magnetrons which are next to each other in the frequency scale satisfy the equation $(\Delta f_i + \Delta f_{i+1})/2$.
6. Baking oven according to one of claims 1 through 5, thereby characterized, that the resonator chamber (16) has a cuboidal design, such that the edge lengths l_x , l_y and l_z of the resonant chamber boundary correspond at least to the 10-fold of the wavelength of the microwave radiation.
7. Baking oven according to one of claims 1 through 5, thereby characterized, that the resonator chamber (16) has a polygonal cross-section.
8. Baking oven according to one of claims 1 through 7, thereby characterized, that the resonator chamber (16) is assembled

of preferably plate-shaped graphite material (16₁ through 16₆).

9. Baking oven according to one of claims 1 through 8, thereby characterized, that for introduction of the microwave energy into the resonator chamber (16) an antenna-arrangement (14) is provided, which has an omnidirectional characteristic.
10. Baking oven according to claim 9, thereby characterized, that the antenna-arrangement (14) is formed as a group emitter comprising multiple individual emitters, which the individual emitters can be supplied by a statistically distributed phase position.
11. Baking oven according to claim 10, thereby characterized, that the group emitter is designed as a slit emitter, which includes a plurality of radiation slits with a slit length of between $\lambda/4$ and $\lambda/2$ and, in comparison thereto, a small slit width w , which viewed in the direction of radiation of the microwave field in the feeding wave guide, are distributed in such a manner over the length thereof, that per slit the same or approximately similar amount of microwave energy can be introduced into the resonant chamber, wherein, viewed in the direction of propagation of the microwave field in the wave guide, the extension of the individual slits corresponds to between w and $\lambda/2$, of which further in the distance measured in the direction of radiation of the microwave field in the wave guide sequential slits of the slit antenna have a value of between $\lambda/2$ and $3\lambda/4$, and, with reference to the center

plane of the wave guide running in the direction of propagation, the sideways separation of the slits from this center plane, over the length of the wave guide, increases stepwise, and wherein a statistic distribution of the longitudinal slits, which form the individual radiation elements, is provided with respect to the longitudinal center plane of the wave guide.

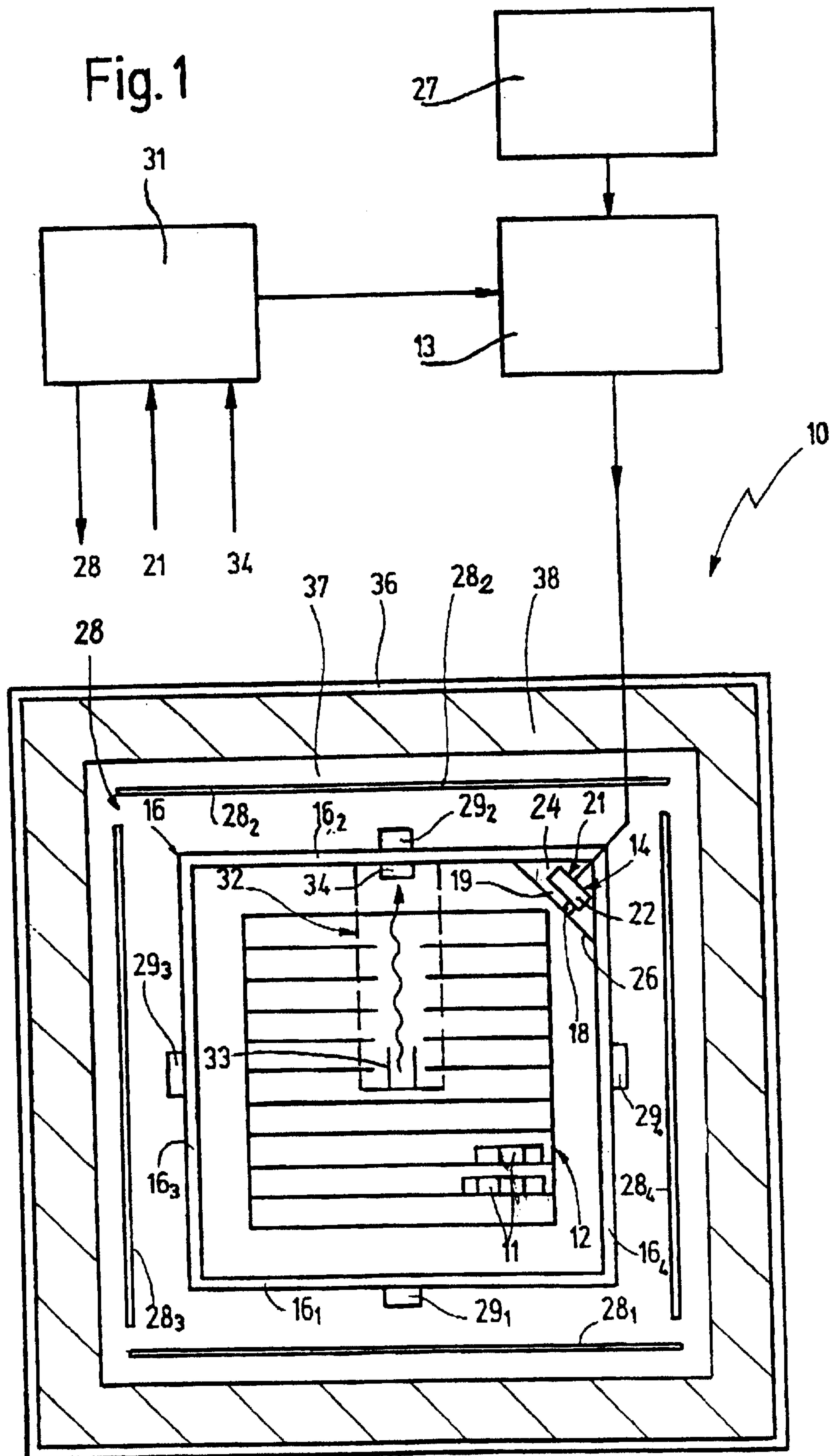
12. Baking oven according to claim 11, thereby characterized, that over the length of the wave guide (21) provided to feed the antenna slits (18) at least 20 individual slits are provided.
13. Baking oven according to claim 12, thereby characterized, that at least some of its slits run perpendicular to the direction of propagation of the microwave field in the wave guide.
14. Baking oven according to one of claims 9 through 13, thereby characterized, that for introduction of the microwave energy into the resonator chamber (16) at least two group emitters are provided, preferably with slit-antenna arrangement (14, 18).
15. Baking oven according to claim 14, thereby characterized, that the group emitters (14) are arranged symmetrically with regard to a significant or distinct axis of the resonator chamber.
16. Baking oven according to one of claims 9 through 15, thereby characterized, that the corresponding antenna-

arrangement (14) is arranged in a strip-shaped edge area of the resonator wall, which runs very close to the inner edge of the resonator wall.

17. Baking oven according to one of claims 1 through 16, thereby characterized, that for the adjustment of a controllable heating device (28) for achievement of equalization of the temperature profile within the resonator chamber, preferably constructed as an electric resistance heater, which maintains the temperature of the resonator walls (16₁ through 16₆) at a value which corresponds to the value of the temperature-value in a central area of pile of material being sintered (12), which is sensed as actual value, preferably via a pyrometer (32), and which for its part in accordance with a control program follows a specific temperature profile over time.
18. Baking oven according to claim 17, thereby characterized, that various wall areas (16₁-16₆) of the resonator chamber (16) are provided with associated temperature sensors (29₁ through 29₆), by means of which the possibly varying resonator wall temperatures may be sensed, and that the heating device (28) includes various heater elements (28₁ through 28₆) for heating the various walls being monitored, which are individually controllable.
19. Baking oven according to one of claims 1 through 18, thereby characterized, that the heat insulating arrangement intended for heat insulation of the resonator chamber (16) against the outer surroundings of the baking oven (10) is formed internal to oven housing (36) for receiving the

resonator chamber (16) and to the heating device (28), and for its part is made of graphite material, in particular graphite felt, with a minimally conductive outer layer.

Fig. 1



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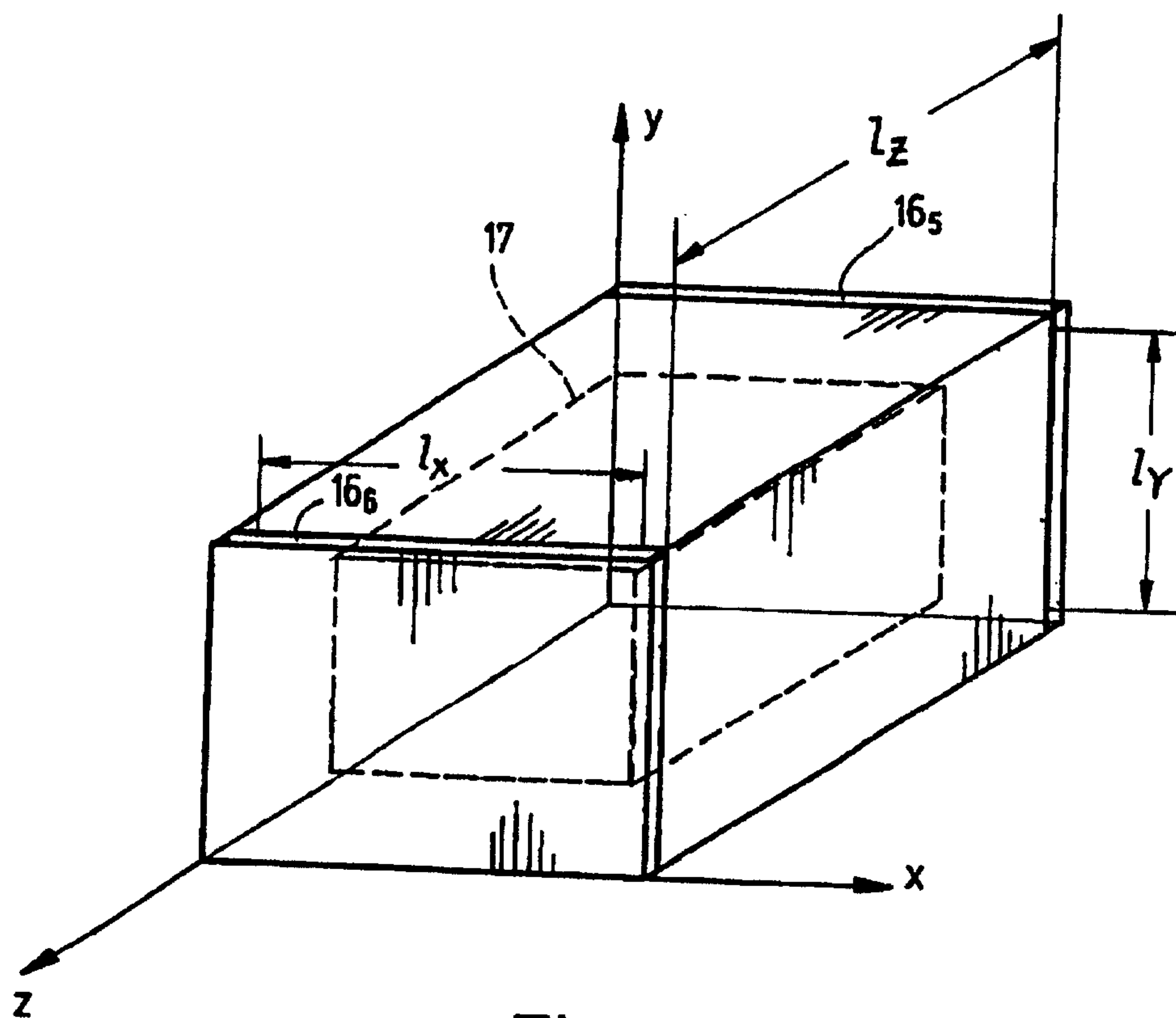


Fig. 1a

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