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Aug. 13, 1974 W. E. LENT ET AL 3,829,403

LIGHTWEIGHT CERAMIC LENS FOR MICROWAVE ANTENNA

Filed July 2, 1970

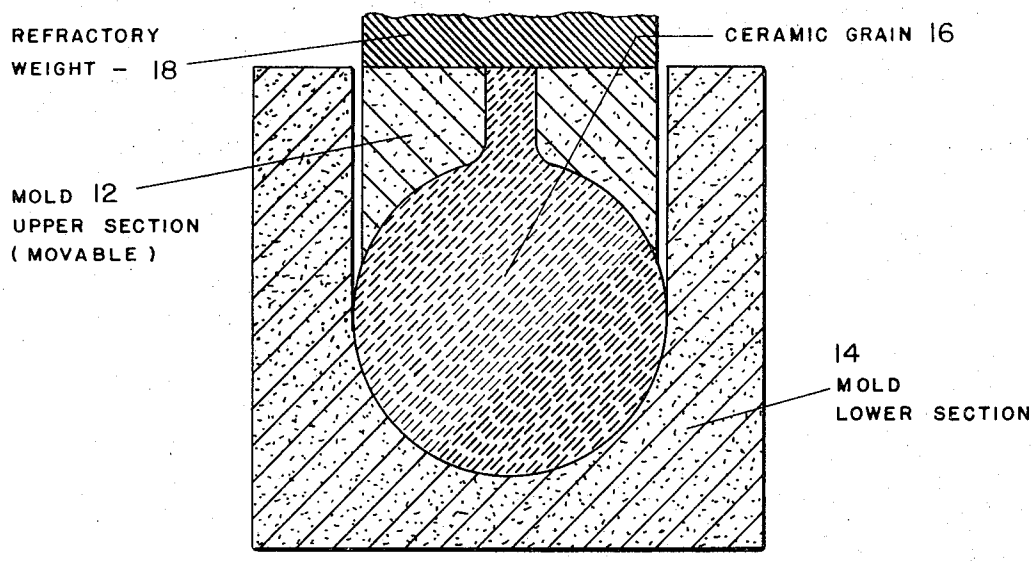


FIG. 1.

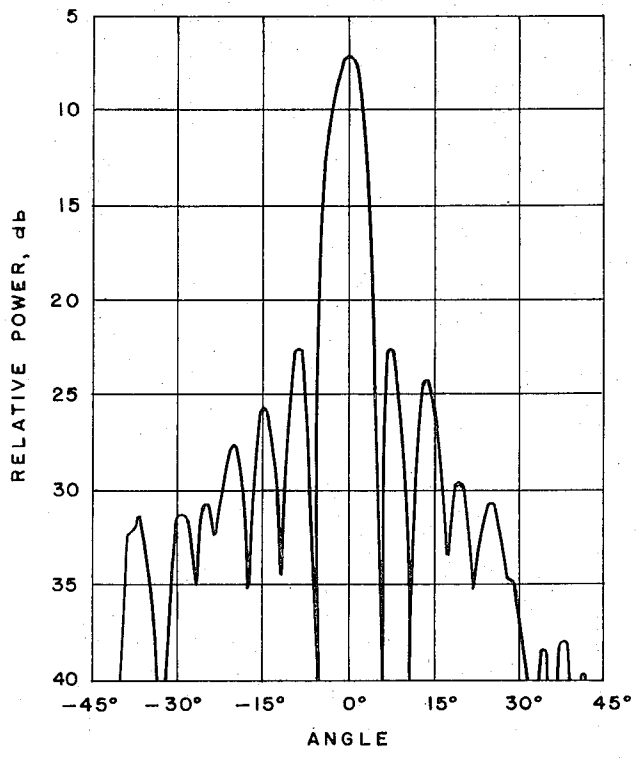


FIG. 2.

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United States Patent Office

3,829,403

Patented Aug. 13, 1974

3,829,403

LIGHTWEIGHT CERAMIC LENS FOR MICROWAVE ANTENNA

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Filed July 2, 1970, Ser. No. 51,875
Int. Cl. C04b 21/06, 35/64
U.S. Cl. 264—44 1 Claim

ABSTRACT OF THE DISCLOSURE

A process for making a lens, generally in the shape of a sphere, composed of a dielectric material having a dielectric constant which may have a value anywhere between 2 and 20, for the specific gravity range of 0.70 to 2.50, suitable for use at a temperature of up to 1200° C., with certain compositions and at frequencies up to microwave frequencies of 100 gHz, comprising the steps of:

(1) preparing a porous, lightweight, ceramic grain;
(2) blending the grain with a mixture of organic and ceramic binders;
(3) forming the material into a desired shape, followed by burning out the organic binders. The forming may take one of two forms:
  (a) hydrostatic pressing in a rubber mold; or
  (b) sintering in a refractory mold, also designated kiln bonding;
(4) dry machining the lens to precise spherical dimensions; and
(5) coating the machined lens with a ceramic or ceramic-plastic sealing system.

material are suitable for use at very high temperatures and at high microwave frequencies. More specifically, this invention relates to a process for making a material suitable for fabrication of a lightweight ceramic microwave lens, generally in a spherical form, and having a diameter of approximately 10 in. This lens is intended to function as an antenna for missiles or aircraft, weighs approximately 15 lb, and is of an opaque yellowish-cream color.

Microwave lenses of the same type in the prior art utilized plastic foams, dielectric-filled plastics or quartz glass to form spherical lenses. The plastic foam Luneberg lens consists of a series of concentric spherical shells. From the innermost shell, each consecutive shell is made up of material having a successively lower dielectric constant, the material having the lowest dielectric constant material comprising the outer shell. The dielectric-filled plastic lenses and the quartz glass lenses have uniform dielectric constants.

A typical 10-inch quartz sphere used as a microwave antenna weighed approximately 42 lbs. The focal point of the quartz lens is fixed and inside the sphere, with resulting pattern distortion and loss of power with an R-F aperture at the sphere surface.

Although the Luneberg and dielectric-filled plastic lenses of the prior art have relatively low density, their permissible operative temperatures are much too low for unprotected missile flight. Also, because of the stepped dielectric construction, the Luneberg lens is limited to lower microwave frequencies.

A more complete comparison of the properties of the material of this invention and that of the prior art is shown in Table 1.

TABLE 1.—COMPARISON OF LENS PROPERTIES

Lens properties	Ceramic lens (invention)	Plastic foam Luneberg lens	Dielectric-filled quartz	
			Plastic lens	Glass lens
Dielectric constant distribution	Constant	Stepped	Constant	Constant.
Upper microwave frequency limits	High, to 100 gHz	Low-limited by steps	Medium, up to 20 gHz	Very high.
Electrical dissipation factor	≷0.001	.0004-.001	.0005-.002	0.0002.
Power handling capability	High	Very low	Low	High.
Side Lobes below main Lobe, db	1-622	20-24	18-22	18-22.
Focus location	Outside or on sphere surface.	Outside sphere surface.	Outside or on sphere surface.	Inside lens (undesirable).
Ability to adjust focal point	Yes	Yes	Yes	No.
Specific gravity	<0.75-2.5	<1.00 average	1-2	2.20.
Operating temperature limits, ° C. (physical consideration only)	500-1,200	150	200	1,200
Mechanical strength for unprotected missile application	High	Very low	Low	Very high.

STATEMENT OF GOVERNMENT INTEREST

The invention described herein may be manufactured and used by or for the Government of the United States of America for governmental purposes without the payment of any royalties thereon or therefor.

BACKGROUND OF THE INVENTION

This invention relates to a process for making a dielectric material having a dielectric constant which may have any of a wide range of values. Certain compositions of the

The specific purpose of this invention is to provide materials and processes for fabricating a spherical ceramic antenna lens. This lens is intended to function in the nose of a missile. It is especially useful because it could possess all the following properties:

(1) Operate with or without a protective radome.
(2) Withstand temperatures up to 1200° C.
(3) Handle considerably more R-F power than plastic foam and plastic-filled lenses.
(4) Allow adjustment or change of dielectric constant by formula change.
(5) Have excellent strength-to-weight ratio.

(6) Produce a well-defined pencil beam radiation pattern as narrow as 2.5 degrees for large diameter spheres, with low side lobes as shown in FIG. 2.
(7) Have a density as low as 0.65 gm/cc.
(8) Exhibit low electrical losses.
(9) Be fabricated at relatively low cost.

SUMMARY OF THE INVENTION

This invention relates to a process for making a dielectric material having a dielectric constant which can have any value between a great range. The material is suitable for use at a temperature which is high enough so that it may be used on high-velocity missiles. The preparation and treatment of the material involves many steps, which it is advantageous to follow in a certain order or sequence.

STATEMENT OF THE OBJECTS OF THE INVENTION

It is an object of the invention to provide a method for fabricating, by molding, and high-temperature firing, a lens with uniformly distributed dielectric constant.

It is another object of the invention to provide a method of making a ceramic lens which can focus an electromagnetic beam either outside of the sphere surface or on the sphere surface.

It is a further object of the invention to provide a material for making a lens suitable for operation on a missile, wherein high temperatures are encountered.

It is still another object of the invention to provide a material for making a ceramic lens with very low electrical dissipation.

It is yet another object of the invention to provide a material for making a ceramic lens with a very low specific gravity, lower than 0.75.

A still further object of the invention is to provide a material which, depending upon the proportion of the various ingredients, has an extremely wide range in the dielectric constant, from 2 to 20, as the specific gravity is adjusted between 0.70 and 2.5.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a cross-sectional view of a refractory ceramic mold.

FIG. 2 is a transmission plot for the lightweight ceramic dielectric material of this invention, specifically of a 4-inch diameter lens.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

This invention relates to two different methods of producing a dielectric material having a wide range of index of refraction. The index of refraction is approximately equal to the square root of the dielectric constant. This invention resulted from an attempt to produce an improved radar lens of a spherical shape, but may be useful in other areas where a light, opaque, and refractory material having an index of refraction between 1.414 and 4.47 is required.

The main steps in the process to produce the lenses are:

(1) Preparation of a very porous lightweight ceramic grain.
(2) Blending of the grain with a mixture of organic and ceramic binders.
(3) Forming a lens, generally in the form of a sphere, which is accomplished by either:
  (a) hydrostatic pressing in a rubber mold, or
  (b) sintering in a refractory mold, also designated kiln bonding.
(4) Dry machining the lens to precise spherical dimensions
(5) Coating the machined lens with a ceramic or ceramic-plastic sealing system.

The hyrostatic press method requires more control of burnout of organic materials than the kiln bonding method. However, kiln bonding requires refractory molds and more complex techniques.

Regardless of which of the two methods are used for the formation of the lens, a prefired grain must first be prepared, prior to firing the sphere. This is necessary to minimize rupture of the sphere during organic burnout and during its firing.

The *first step* in the fabrication of the prefired grain is the preparation of a ceramic slip (a thick liquid).

The general formula range for the ceramic slip is shown in the second column, while the specific percentage weights for a dielectric constant of 3.25–3.40 and a specific gravity of 0.70–0.80 is given in the third column.

TABLE 2

	Weight percent	
Titanium dioxide TiO_2	20–80	70
Silica	0–40	10
Boron phosphate	0–15	0
Ball clay (hydrated aluminum silicate)	5–15	15
Alumina	0–20	0
Glass frit "F"	0–10	5
Water	30–50	40

To increase operating temps., the glass frit and boron phosphate may be eliminated, the density of the resultant composition decreases, while increasing the amount of alumina. Moreover, the resultant lens is less lossy electrically. The gain of the antenna using the boron phosphate ceramic bond was 18–20 db and with the glass frit bond is 28 db.

The formula for glass frit "F," premelted at 1450° C. and water-quenched, then ball-milled to pass a 325-mesh screen, is a follows:

TABLE 3

	Weight percent
Calcium oxide, CaO	1–4
Magnesium oxide, MgO	13–18
Alumina, Al_2O_3	10–15
Boric Acid, H_3BO_3	20–30
Silica, SiO_2	35–50

A proper formula selection from the ranges given in Tables 2 and 3 will make possible the required dielectric constant of 3.0 to 3.4 with a possible density range of 0.6 to 1.2 gm./cc. The dielectric constant of the material must be within the range of 3.25 to 3.40, irrespective of the composition of the material or the lens diameter for the microwave energy to be focused on or near the surface of the lens.

With an increase in the dielectric constant above the value of 3.4, the dielectric lens may focus the electromagnetic energy within the sphere, as does a quartz dielectric lens having this value. This causes power loss, optical aberration, and the R-F aperture is difficult to locate inside the lens.

The dielectric constant, at a given density, may be adjusted by changing the ratio of titanium dioxide to silica or alumina. Specific gravity and fired hardness are decreased by lowering the percentages of boron phosphate, glass frit, and ball clay and lower forming pressures. The composition, however, must be such that the lens have a low loss electrically. Although, for the specific application and the specific frequencies for which the material was designed it was desirable to have a dielectric constant of approximately 3.25, by the process disclosed herein a composition may be formulated having a dielectric constant of any value from 2 to 20, and even greater. As the dielectric constant becomes large, the density of the material increases drastically.

The *second main step* in the process to produce the ceramic lenses involves blending the following thoroughly in a paddle-type blender:

TABLE 4

	Weight percent
Ceramic slip (from step 1)	38–60
Stearic acid powder, —100 mesh	30–60
Enough water to create a *very thick*, smooth paste.	

All of the components of the ceramic slip listed in Table 2 and the components listed in Table 4 could be mixed together in one container, but it is much more difficult to thoroughly blend the lens material in this way. A Hobart mixer, ordinarily used for mixing cakes in bakeries, was used for mixing the ingredients itemized in Table 4. The mixer has a big paddle which moves in a figure-of-eight motion, and blends all the ingredients. The consistency of the resultant paste is approximately that of a thick biscuit dough.

The second main step also involves the process of grain formation which includes the steps of:

(1) Removing water from the paste by drying on an absorbent surface or filter pressing to 6–15% moisture;
(2) Extruding, while plastic, through a 28-mesh screen by any mechanical means;
(3) Drying extruded, elongated, pellets until they can be reduced to approximately 28 mesh grain by a short period of slow tumbling;
(4) Slowly tumbling for 3–10 minutes to approximate 28-mesh screen size grain;
(5) Drying the screened grain with warm circulating air not to exceed 150° F.; and
(6) Gently removing all fines smaller than 35-mesh.

The next operation consists of grain sintering, which involves:

(1) Spreading dried, sized, selected grain on a 100 mesh stainless steel screen;
(2) Holding the screen and grain, on passing them through, in a hot gas flame until the grain is charred quickly with a minimum of stearic acid melting; ignition of grain to carbonization is necessary to prevent melting and deformation before firing to maturity;
(3) After charring, sintering in a refractory sagger to 1000–1800° C. for one hour. The temperature choice depends upon the ceramic slip formula, which is selected for the anticipated use temperature of the lens.

The final operation in the second main step involves grain sizing, or gently breaking up the grain as required, and rescreening through a 28-mesh screen and removing all fines less than 35 mesh.

The *third main step*, that of fabricating a lens, and describing first the hydrostatic forming method, involves

(A) Blending in a paddle type mixer at slow speed:

	Weight percent
2% aqueous Methocel solution	15–30
—325-mesh powdered glass frit "F"	8–25

(B) Allowing the Methocel and glass frit to remain in mixing container, and slowly adding the prefired ceramic grain, while blending slowly so as to thoroughly coat the grain without saturating it; 75–90%;
(C) Filling the rubber mold with grain immediately after coating so as not to lose moisture;
(D) Evacuating air from the mold;
(E) Hydrostatically pressing the above evacuated mixture to 100–1000 p.s.i., depending upon desired density;
(F) Removing the mold;
(G) Burning out the organics in vented oven, from room temperature to 400° C., not to exceed 10° C./hour temperature rise; and
(H) Sintering to final temperautre, 900–1600° C., depending upon formula and desired use temperature.

Methocel is a hydroxy ethyl cellulose, manufactured by the Dow Chemical Company, Midland, Mich.

Lens fabrication by the kiln bonding method involves the following steps:

(A) Identical to steps A and B of hydrostatic forming method;
(B) Drying completely and rescreening to separate;
(C) Filling refractory ceramic mold **12** and **14**, as shown in FIG. 1, and vibrating grains **16** into place; and after placing refractory weight **18** on mold **12**;
(D) Sintering mold and grain sufficiently to join prefired grains with glass from the grain coating; and
(E) Removing sintered sphere from mold.

The *fourth main step* in fabricating the ceramic lens involves dry machining the sphere to precision lens dimensions.

Finally, *the last main step* in the fabrication involves coating the machined sphere, as follows:

(A) Base Layer:
(1) The following are ball milled for 1 hour:

	Weight percent
Prefired grain, 35 mesh to fine	92–100
Glass Frit "F"	0–8
Enough water for spraying consistency	

(2) A spray or paint coating of the above mixture is deposited on the lens.
(3) The lens is sintered at 800 to 1300° C., depending on ceramic formula.

(B) Sealing Layer:

The base layer surface is sealed with a ceramic glaze or with a Teflon spray. A typical formula for ceramic sealing glass, fritted at 1350–1400° C. and water quenched, is shown immediately below:

	Weight, percent
Potassium oxide, K_2O	0–2
Magnesium oxide, M_gO	1–4
Calcium oxide, CaO	2–4
Alumina, Al_2O_3	3–7
Barium oxide, BaO	6–8
Boric acid, H_3BO_3	16–20
Lead oxide, PbO	25–30
Silica, SiO_2	30–35

Coating the sphere is necessary to: (1) increase lens strength; (2) prevent surface erosion; (3) seal out moisture; and (4) provide a dielectric transition from the lens surface to air.

The process of lens formation, while it does involve some chemical reaction, such as oxidation, is primarily physical. The percentages of the various components in the final product is approximately the same as those in the original prefired material, within a few percent. Of course the organic components, including the gums and water, vanish with the firing. While the fired components are approximately the same as the unfired components, they could not be used again, even if ground up after having been fired, because they have lost their plasticity.

After exposure to heat, including the prefiring, the resultant end product, excluding the added water, weighed only 1% less due to burnout of organic material. As a result, the final product has less of a fracture problem than compositions which have a larger proportion of burn-out components.

Hydrostatic forming with a damp organic-glass-prefired grain mixture is preferred over the kiln bonding technique for forming.

In general if the prefired grain matures at temperature x° C., the sphere will be fired at $x-50$° C., the sealing subcoat at $x-100$° C., and the sealing glass at $x-150$° C.

It can be pointed out that the mold geometry of FIG. 1 may be changed to produce a solid cylinder which may be machined into a sphere after bonding.

What is claimed is:

1. A process for making a lens composed of a dielectric material having a dielectric constant which has a value

between 2 and 20 for the specific gravity range of 0.70–2.5, suitable for use at a temperature of up to 1200° C. and at frequencies up to microwave frequencies of 100 gHz., comprising the steps of:

providing a porous, ceramic grain;

blending the grain with a mixture of organic and ceramic binders;

forming the material into a desired shape;

burning out the organic binders; and

sintering the material into a strong ceramic; wherein the steps of providing a porous grain compromise:

milling for approximately four hours in a porcelain ball mill the following ingredients forming a ceramic slip:

	Weight percent
Titaniumdioxide, TiO_2	20–80
Silica, SiO_2	0–40
Ball clay (hydrated aluminum silicate)	5–15
Alumina, Al_2O_3	0–20
Boron phosphate	0–15
Glass frit "F"	0–10
Water	30–50

blending the following percentages of materials thoroughly in paddle-type blender:

	Weight percent
Ceramic slip (from above)	38–60
Stearic acid powder	30–60
Enough water to create a thick, smooth, paste	

the steps of providing a porous, lightweight, ceramic grain further comprising the step of grain formation, which includes the following steps:

(1) removing water from the paste by drying on an absorbent surface or filter pressing to 6–15% moisture:

(2) extruding, while plastic, through a 28 mesh screen by any mechanical means;

(3) drying extruded, elongated, pellets until they can be reduced to approximately 28 mesh grain by a short period of slow tumbling;

(4) slowly tumbling 3–10 minutes—to approximate 28 mesh screen size grain;

(5) drying the screened grain with warm circulating air not to exceed 150° F.; and

(6) removing all fines smaller than 35 mesh;

the step of forming includes charring the organic binder, which further involves the following steps:

(1) spreading dried, sized, selected grain on a 100-mesh stainless steel screen;

(2) holding the screen and grain in a gas flame until the grain is charred quickly with a minimum of stearic acid melting;

(3) after burnout, sintering in a refractory sagger to 1000–1800° for one hour, the temperature choice depending upon the ceramic slip formula and the desired lens use temperature;

(4) breaking up grain and rescreening through a 28-mesh screen, removing all fines less than 35 mesh;

dry-machining the lens to precise spherical dimensions; and coating the machined lens with a ceramic sealing layer.

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U.S. Cl. X.R.

264—49, 60, 67, 332; 343—909