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MONOLITHIC CERAMIC CAPACITOR

FIELD OF THE INVENTION

This invention relates to a ceramic capacitor,
more particularly a monolithic ceramic capacitor having
5 internal electrodes made of nickel or a nickel alloy.

BACKGROUND OF THE INVENTION

A monolithic ceramic capacitor is generally
produced according to the following procedures.
Dielectric ceramic layers in sheet form [each] having
10 applied thereon an electrode material [serving] to serve
as an internal electrode are prepared. A ceramic
material mainly comprising, e.g., BaTiO_3 , is used as a
dielectric ceramic layer. A plurality of the dielectric
ceramic layers with the electrode material are piled up
15 and press-bonded under heat into one body. The resulting
laminate is calcined [in a natural atmosphere] at 1250 to
1350°C to obtain a ceramic laminate having internal
electrodes. An external electrode is baked onto both
sides of the ceramic laminate to make an electrical
20 connection to the internal electrodes [to] and obtain a
monolithic ceramic capacitor.

The material for the internal electrodes are
required to satisfy the following conditions:

1. To have a melting point at or above the
25 calcining temperature of the ceramic laminate because the
internal electrodes and the ceramic laminate are calcined
simultaneously.

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- 2 -

2. To be [insusceptible] resistant to oxidation in a high-temperature oxidative atmosphere and be unreactive with the dielectric ceramic layer.

5 Noble metals, such as platinum, gold, palladium[,] and a silver-palladium alloy, have been used as an electrode material satisfying these requirements. While excellent in performance, these electrode materials are so expensive that the proportion of the electrode material cost reaches 30 to 70% of [all] the entire
10 material cost, which has been the greatest factor of increasing the production cost of monolithic ceramic capacitors.

In addition to noble metals, base metals, such as Ni, Fe, Co, W[,] and Mo, also have a high melting
15 point. However, these base metals are readily oxidized in a high-temperature oxidative atmosphere, [failing] causing them to fail to perform [the] their function as an electrode. Therefore, calcination of the base metal together with dielectric ceramic layers must be carried
20 out in a neutral or reducing atmosphere before [it] they can be used as an internal electrode of a monolithic ceramic capacitor. However, the problem is that a conventional dielectric ceramic material undergoes vigorous reduction into a semiconductor if calcined in a
25 neutral or reducing atmosphere.

Dielectric ceramic materials which have been proposed in order to solve the above problem include a dielectric ceramic material comprising a barium titanate solid solution having a barium site to titanium site
30 ratio in excess of a stoichiometric one (see JP-B-57-42588, the term "JP-B" as used herein means an "examined published Japanese patent application") and a dielectric ceramic material comprising a barium titanate solid

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- 3 -

solution having incorporated therein an oxide of a rare earth metal, such as La, Nd, Sm, Dy or Y (see JP-A-61-101459, the term "JP-A" as used herein means an "unexamined published Japanese patent application").

5 . On the other hand, dielectric ceramic materials whose dielectric constant has reduced temperature dependence, such as [a] BaTiO₃-CaZrO₃-MnO-MgO system (see JP-A-62-256422) and [a] BaTiO₃-(Mg, Zn, Sr or Ca)O-B₂O₃-SiO₂ system (see JP-B-61-14611), have also been proposed.

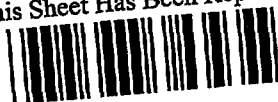
10 Use of these dielectric ceramic materials have made it possible to obtain a ceramic laminate that is not transformed into a semiconductor even when calcined in a reducing atmosphere, thereby making it feasible to produce a monolithic ceramic capacitor in which a base
15 metal, such as nickel, is used as an internal electrode.

 In recent years, size reduction of electronic components has [been] accelerated rapidly [with] in the development of electronics. Monolithic ceramic capacitors have also showed a remarkable tendency to
20 reduction in size and increase in capacity. There has thus been an increasing demand for a dielectric ceramic material which has a high dielectric constant, shows reduced variation in dielectric constant with temperature change, and is thereby highly reliable.

25 The dielectric ceramic materials disclosed in JP-B-57-42588 and JP-A-61-101459 exhibit a high dielectric constant but have a large crystal grain size on calcination. When they are applied to a monolithic ceramic capacitor in which each dielectric ceramic layer
30 has [such] a small thickness such as 10 μm or less, the number of crystal grains existing per layer is decreased, resulting in diminished reliability. Besides, these materials undergo considerable variation in dielectric

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constant with temperature change and are not regarded to meet the [demand] demands of the market sufficiently.

5 The dielectric ceramic material disclosed in JP-A-62-256422, on the other hand, exhibits a relatively high dielectric constant and provides[,] on calcination, a ceramic laminate having a small crystal grain size and [showing] small variation of dielectric constant with temperature change. However, CaZrO_3 and CaTiO_3 produced on calcination tend to form a secondary phase together with MnO , etc., which has made the resulting monolithic ceramic capacitor less reliable in high temperatures.

10 The dielectric ceramic material disclosed in JP-B-61-14611 exhibits a dielectric constant of 2000 to 2800, which is disadvantageous for achieving size reduction and capacity increase [of] in a monolithic ceramic capacitor. Moreover, the material fails to fulfill the requirement of X7R characteristics specified by EIA (Electronic Industries Association) [Standards] standards that the percentage of change in electrostatic capacity be within a range of $\pm 15\%$ in [a] the temperature range of from -55°C to $+125^\circ\text{C}$.

15 Although JP-A-5-9066, JP-A-5-9067, and JP-A-5-9068 have proposed ceramic compositions in order to eliminate these problems, the ever-continuing demand for size reduction and capacity increase has been producing a keen demand for dielectric ceramic materials with greater reliability. At the same time, demand for thickness reduction of a ceramic dielectric layer has been getting intenser.

20 Thus, there has been the necessity for the development of a small-sized and high-capacity monolithic ceramic capacitor having excellent reliability in a high temperature and high humidity environment.

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SUMMARY OF THE INVENTION

An object of the present invention is to provide an economical, small-sized and high-capacity monolithic ceramic capacitor which has a dielectric constant of 3000 or higher and an insulation resistance as high as 6000 MΩ·μF or more at room temperature or 2000 MΩ·μF or more at 125°C, as expressed in terms of the product of capacitance and insulation resistance (CR product), and whose capacity exhibits temperature characteristics satisfying the B characteristics specified by JIS (Japanese Industrial Standards) and the X7R characteristics specified by EIA standards, and which has excellent weathering performance in, for example, loading in high temperature or high humidity.

The present invention provides a monolithic ceramic capacitor having a laminate of a plurality of dielectric ceramic layers, a plurality of internal electrodes each formed between [every] two adjacent dielectric ceramic layers in such a manner that one end of each internal electrode is exposed at one end of the dielectric ceramic layer alternately, and a pair of external electrodes each electrically connected to the plurality of exposed internal electrodes [on each side] of the laminate, in which the dielectric ceramic layer comprises (a) barium titanate having an alkali metal oxide impurity content of not more than about 0.02% by weight, (b) at least one member selected from the group consisting of scandium oxide and yttrium oxide, (c) at least one member selected from the group consisting of gadolinium oxide[,] terbium oxide[,] and dysprosium oxide, (d) manganese oxide, (e) cobalt oxide[,] and (f) nickel oxide, and is made up of a material containing (1)

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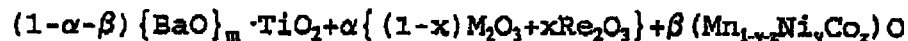
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- 6 -

100 mol of a main component represented by the
compositional formula:



wherein M_2O_3 represents at least one member selected from
the group consisting of Sc_2O_3 and Y_2O_3 ; Re_2O_3 represents at
least one member selected from the group consisting of
 Gd_2O_3 , Tb_2O_3 , and Dy_2O_3 ; $0.0025\leq\alpha\leq0.025$; $0.0025\leq\beta\leq0.05$;
 $\beta/\alpha\leq4$; $0<x\leq0.50$; $[0\leq y\leq1.0; 0\leq z\leq1.0]$ $0\leq y\leq1.0; 0\leq z\leq1.0$;
 $0\leq y+z\leq1.0$; and $1.000\leq m\leq1.035$, (2) about 0.5 to 5.0 mol,
in terms of MgO, of magnesium oxide as a secondary
component, and (3) about 0.2 to 3.0 parts by weight, per
100 parts by weight of the total weight of the main
component (1) and the secondary component (2), of SiO_2 -
 TiO_2 -MO-based oxide glass (wherein MO represents at least
one member selected from the group consisting of BaO,
CaO, SrO, MgO, ZnO, and MnO), and the internal electrodes
are made up of nickel or a nickel alloy.

In a preferred embodiment of the monolithic
ceramic capacitor of the present invention, the
composition of the SiO_2 - TiO_2 -MO-based oxide glass is, when
plotted on a triangular diagram of (SiO_2 , TiO_2 , MO)
(wherein MO is as defined above), in the area surrounded
by, or on, four straight lines connecting four points: A
(85,1,14), B (35,51,14), C (30,20,50), and D (39,1,60)
(unit: mol%), and contains at least one of Al_2O_3 and ZrO_2
in a total amount of not more than about 15 parts by
weight per 100 parts by weight of the (SiO_2 , TiO_2 , MO)
component, provided that the amount of ZrO_2 is not more
than about 5 parts by weight.

In another preferred embodiment, the external
electrode is made up of a sintered layer of an
electrically conductive metal powder which may contain

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- 7 -

glass [frits] frit. In a still preferred embodiment,
the external electrode is composed of a first layer made
of a sintered layer of an electrically conductive metal
powder which may contain glass [frits] frit and a second
5 layer that is formed on the first layer by plating.

BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 is a schematic cross section of a
monolithic ceramic capacitor according to one embodiment
of the present invention.

10 Fig. 2 is a schematic plan of a ceramic layer
with an internal electrode which is used in the
monolithic ceramic capacitor of Fig. 1.

Fig. 3 is a perspective exploded view of the
ceramic laminate used in the monolithic ceramic capacitor
15 of Fig. 1.

Fig. 4 is a triangular diagram of (SiO_2 , TiO_2 ,
MO) showing a preferred range of the composition of SiO_2 -
 TiO_2 -MO-based oxide glass.

DETAILED DESCRIPTION OF THE INVENTION

20 In the monolithic ceramic capacitor of the
present invention, the dielectric ceramic layers are
obtained by calcining a dielectric ceramic material
comprising (1) (a) barium titanate, (b) at least one of
scandium oxide and yttrium oxide, (c) at least one of
25 gadolinium oxide, terbium oxide[,] and dysprosium oxide,
(d) manganese oxide, (e) cobalt oxide[,] and (f) nickel
oxide at a ratio shown by the above-described
compositional formula having incorporated therein (2)
magnesium oxide and (3) SiO_2 - TiO_2 -MO-based oxide glass
30 (wherein MO represents at least one member selected from
the group consisting of BaO, CaO, SrO, MgO, ZnO, and

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- 8 -

MnO). The dielectric ceramic material can be calcined in a reducing atmosphere without suffering from deterioration of characteristics to provide a highly reliable monolithic ceramic capacitor whose capacity exhibits temperature characteristics satisfying the B characteristics specified by JIS and the X7R characteristics specified by EIA standards, and which exhibits high insulation resistance at room temperature and high temperature.

In the resulting dielectric ceramic laminate, the crystal grains are as small as 1 μm or less so that the grains increase in number per layer. This will secure a sufficient reliability even though the thickness of the dielectric ceramic layer in the laminate is reduced.

The barium titanate constituting the main component (1) contains, as impurities, alkaline earth metal oxides (e.g., SrO and CaO), alkali metal oxides (e.g., Na₂O and K₂O), and other oxides (e.g., Al₂O₃ and SiO₂). Of these impurities, the alkali metal oxides, such as Na₂O and K₂O, have been confirmed to be greatly influential on the electrical characteristics. It was proved that a dielectric constant of not smaller than 3000 can be obtained by using barium titanate having an alkali metal oxide content of not more than about 0.02% by weight and preferably about 0.012% or less.

It has also been found that incorporation of oxide glass mainly comprising SiO₂-TiO₂-MO (wherein MO is at least one member selected from the group consisting of BaO, CaO, SrO, MgO, ZnO, and MnO) into the dielectric ceramic layers brings about improved sintering properties and improved resistance to plating. Further, addition of

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- 9 -

Al_2O_3 and/or ZrO_2 to the oxide glass makes it possible to obtain higher insulation resistance.

Dielectric ceramic layers made from the above-described dielectric ceramic material provide a highly reliable, small-sized, and high-capacity monolithic ceramic capacitor, the capacity of which shows reduced variation with temperature. Use of the dielectric ceramic material makes it feasible to use nickel or a nickel alloy as an internal electrode. It is also possible to use nickel or a nickel alloy in combination with a small amount of ceramic powder.

The external electrode is not particularly limited in composition. For example, it can be a sintered layer of a conductive powder of various metals (e.g., Ag, Pd, Ag-Pd, Cu[,] and Cu alloys) or a sintered layer of a mixture of such a conductive metal powder and glass frits of various kinds (e.g., B_2O_3 - Li_2O - SiO_2 -BaO-based glass frits, B_2O_3 - SiO_2 -BaO-based glass frits, Li_2O - SiO_2 -BaO-based glass frits, B_2O_3 - SiO_2 -ZnO-based glass frits). Ceramic powder may be used in a small proportion with the conductive metal powder (and glass frits). It is preferable that the sintered layer is plated with Ni, Cu, an Ni-Cu alloy, etc. The plated layer may further be plated with solder, tin, etc.

A monolithic ceramic capacitor according to one embodiment of the present invention will be described by referring to the accompanying drawings.

Fig. 1 is a schematic cross section of the monolithic ceramic capacitor. Fig. 2 is a schematic plan of a ceramic layer having an internal electrode used in the monolithic ceramic capacitor of this embodiment. Fig. 3 is a perspective exploded view of the ceramic

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- 10 -

laminate used in the monolithic ceramic capacitor of this embodiment.

As shown in Fig. 1, the monolithic ceramic capacitor 1 is of rectangular chip type having a ceramic laminate 3 composed of a plurality of dielectric ceramic layers 2a and 2b, with an internal electrode 4 being interposed between every two ceramic layers. On each side of the ceramic laminate 3 are formed an external electrode 5, a first plating layer 6 formed by plating with nickel, copper, etc., and a second plating layer 7 formed by plating with solder, tin, etc.

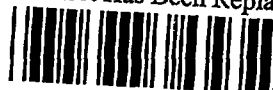
The monolithic ceramic capacitor 1 shown in Fig. 1 can be produced as follows.

(1) A main component comprising (a) barium titanate, (b) at least one of scandium oxide and yttrium oxide, (c) at least one of gadolinium oxide, terbium oxide[,] and dysprosium oxide, (d) manganese oxide, (e) cobalt oxide [,] and (f) nickel oxide, (2) magnesium oxide, and (3) $\text{SiO}_2\text{-TiO}_2\text{-MO}$ -based oxide glass (wherein MO is as defined above) are compounded together with a binder and a solvent into a slurry and molded to prepare a dielectric ceramic layer 2 (green sheet). An internal electrode 4 [is formed] of nickel or a nickel alloy is formed on one side of the dielectric ceramic layer 2 by screen printing, vacuum evaporation or plating to obtain a dielectric ceramic layer 2b having an internal electrode 4 as shown in Fig. 2.

A requisite number of the dielectric ceramic layers 2b are piled up and press-bonded in between a pair of dielectric ceramic layers 2a having no internal electrode to obtain a laminate as shown in Fig. 3. The laminate of the dielectric ceramic layers 2a, 2b.[..

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- 11 -

2b], 2b, 2a is calcined in a reducing atmosphere at a prescribed temperature to form a ceramic laminate 3.

5 An external electrode 5 is then formed on each side of the ceramic laminate 3 to make an electrical connection to the internal electrodes 4. The external electrodes 5 can be made of the same material as used for the internal electrodes 4. In addition, silver, palladium, [a] silver-palladium alloy, copper, [a] copper alloy, etc. are also useful. These metal powders may be
10 used in combination with glass frits, such as B_2O_3 - SiO_2 -BaO-based glass frits or Li_2O - SiO_2 -BaO-based glass frits. The material of the external electrode should be selected appropriately taking into consideration the use of the resulting monolithic ceramic capacitor, the place of use,
15 and the like. The external electrodes 5 can be formed by applying a paste of the metal powder selected to the ceramic laminate 3 (i.e., a calcined laminate) followed by baking. Alternatively, the paste may be applied to the laminate of the green sheets before calcination and
20 baked to form the electrodes 5 and the ceramic laminate 3 simultaneously.

The external electrodes 5 are then plated with nickel, copper, etc. to form a first layer 6. Finally, the first layer 6 is plated with solder, tin, etc. to
25 form a second layer 7, thereby to produce a monolithic ceramic capacitor 1 of the chip type.

As described above, the ceramic material used in the present invention does not undergo reduction and therefore does not change into a semiconductor even if
30 calcined in a reducing atmosphere, which allows use of a base metal (nickel or a nickel alloy) as an electrode material. Further, calcination of the ceramic material can be achieved at a relatively low temperature of not

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- 12 -

higher than 1300°C. As a result, both the material cost and the process cost of monolithic ceramic capacitors can be reduced.

5 The monolithic ceramic capacitor according to the present invention exhibits excellent characteristics, having a dielectric constant of not smaller than 3000, showing reduced variation in dielectric constant with temperature change, having a high insulation resistance, and undergoing no deterioration in characteristics under
10 a high temperature or high humidity condition.

The grain size of the dielectric ceramic material according to the present invention is as small as about 1 μ m or less. Therefore, if the thickness of dielectric ceramic layers constituting a monolithic
15 ceramic capacitor is reduced, each layer can have a greater number of crystal grains than in conventional, monolithic ceramic capacitors. There is thus provided a highly reliable, small-sized, and yet high-capacity monolithic ceramic capacitor.

20 The present invention will now be illustrated in greater detail with reference to Examples, but it should be understood that the present invention is not construed as being limited thereto.

EXAMPLE 1

25 TiCl_4 and $\text{Ba}(\text{NO}_3)_2$, both having [a] varied purity were weighed and treated with oxalic acid to precipitate barium titanyl oxalate ($\text{BaTiO}(\text{C}_2\text{O}_4) \cdot 4\text{H}_2\text{O}$). The precipitate was thermally decomposed at or above 1000°C to synthesize 4 species of barium titanate (BaTiO_3) shown
30 in Table 1 below.

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- 13 -

Table 1						
Kind of BaTiO ₃	Content of Impurities (wt%)					Average Particle Size (μm)
	Alkali Metal Oxide	SrO	CaO	SiO ₂	Al ₂ O ₃	
A	0.003	0.012	0.001	0.010	0.005	0.60
B	0.020	0.010	0.003	0.019	0.008	0.56
C	0.012	0.179	0.018	0.155	0.071	0.72
D	0.062	0.014	0.001	0.019	0.004	0.58

Oxides, carbonates or hydroxides of silicon, titanium, barium, strontium[,] and manganese were [weighted] weighed and mixed so as to give an SiO₂:TiO₂:BaO:SrO:MnO molar ratio of 0.60:0.25:0.10:0.02:0.03. The mixture was ground and evaporated to dryness to obtain powder. The powder was melted by heating in an aluminum crucible at 1300°C, quenched, and ground to obtain powdered oxide glass having an average particle size of not greater than 1 μm.

[A composition] The compositions shown in Table 2 below [was] were compounded from (i) the barium titanate of Table 1, (ii) the powdered oxide glass prepared above, (iii) BaCO₃ serving for adjustment of the Ba/Ti molar ratio of barium titanate[,] and (iv) Sc₂O₃, Y₂O₃, Gd₂O₃, Tb₂O₃, Dy₂O₃, MnCO₃, NiO, Co₂O₃[,] and MgO₂ each having a purity of not lower than 99%.

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- 14 -

Table 2

Table 2																			
Sample No.	[(1-α-β){BaO} ₂ •TiO ₂ +α{(1-x)M ₂ O ₃ +xReO ₃ }+β(Mn _{1-x} Ni _x Co ₂ O)}																	MgO (mol %**)	Amount of Oxide Glass (part by weight***)
	Kind of BaTiO ₃	α	M		1-x	Re			x	β	β/α	y	z	y+z	m				
			Sc	Y		Gd	Tb	Dy											
1*	A	0.0000								0.00300		0.10	0.30	0.40	1.015	1.00	0.80		
2*	A	0.0120		0.80		0.20			0.20	0.0000					1.010	1.20	1.00		
3*	A	0.0100		1.00					0.00	0.0200	2.0	0.10	0.10	0.20	1.005	0.80	1.00		
4*	A	0.0150		0.80					0.20	0.0300	2.0	0.20	0.20	0.40	0.990	1.00	1.00		
5*	A	0.0150		0.70					0.30	0.0450	3.0	0.20	0.30	0.50	1.000	0.80	1.00		
6*	A	0.0200		0.80					0.20	0.0200	1.0	0.30	0.10	0.40	1.015	0.20	0.80		
7*	A	0.0150	0.10	0.70					0.20	0.0300	2.0	0.10	0.10	0.20	1.005	1.20	0.00		
8	A	0.0025		0.80		0.10			0.20	0.0025	1.0	0.10	0.10	0.20	1.010	1.00	0.20		
9	A	0.0250		0.70					0.30	0.0500	2.0	0.10	0.30	0.40	1.005	0.80	1.20		
10	A	0.0060	0.10	0.70				0.20	0.20	0.0240	4.0	0.10	0.30	0.40	1.010	1.20	1.00		
11	B	0.0100	0.50						0.50	0.0150	1.5	0.20	0.30	0.50	1.020	1.50	1.20		
12	C	0.0100		0.90					0.10	0.0050	0.5	0.00	0.50	0.50	1.010	1.00	1.00		
13	A	0.0150		0.80		0.20			0.20	0.0300	2.0	0.10	0.00	0.10	1.005	0.50	1.00		

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- 15 -

Sample No.	Kind of BaTiO ₃	α	M		1-x	Re				x	β	β/α	y	z	y+z	m	MgO (mol %**)	Amount of Oxide Glass (part by weight***)	
			α	Kind of BaTiO ₃		Sc	Y	Gd	Tb										Dy
14	A	0.0050			0.70	0.70			0.10	0.20	0.30	0.0150	3.0	0.00	0.00	1.005	5.00	1.20	
15	A	0.0100			0.80	0.80	0.10	0.10		0.20	0.0300	3.0	0.10	0.30	0.40	1.035	0.80	1.20	
16	A	0.0100			0.80	0.80	0.10	0.05	0.05	0.20	0.0200	2.0	0.10	0.10	0.20	1.010	1.00	3.00	

Table 2 - Cont'd.																			
Sample No.	Kind of BaTiO ₃	α	M		1-x	Re				x	β	β/α	y	z	y+z	m	MgO (mol %**)	Amount of Oxide Glass (part by weight***)	
			α	Kind of BaTiO ₃		Sc	Y	Gd	Tb										Dy
17*	A	0.0300			0.80	0.80	0.20			0.20	0.0450	1.5	0.10	0.10	0.20	1.010	1.00	1.50	
18*	A	0.0200			0.80	0.80			0.20	0.20	0.0700	3.5	0.20	0.40	0.60	1.010	0.80	1.00	
19*	A	0.0050			0.70	0.70	0.10		0.20	0.30	0.0300	6.0	0.10	0.10	0.20	1.015	1.00	0.80	
20*	A	0.0150			0.20	0.20	0.80			0.80	0.0150	1.0	0.10	0.30	0.40	1.010	1.00	1.20	
21*	A	0.0150			0.80	0.80		0.20		0.20	0.0300	2.0	0.00	1.00	1.00	1.010	1.00	1.00	
22*	A	0.0050	0.10	0.70	0.80	0.80	0.20			0.20	0.0150	3.0	1.00	0.00	1.00	1.010	0.80	1.00	
23*	A	0.0100			0.70	0.70			0.30	0.30	0.0150	1.5	0.40	0.60	1.00	1.010	1.20	1.20	
24*	A	0.0100	0.20	0.60	0.80	0.80			0.20	0.20	0.0300	3.0	0.20	0.20	0.40	1.050	0.80	1.20	
25*	A	0.0100			0.70	0.70	0.30			0.30	0.0250	2.5	0.10	0.10	0.20	1.005	7.00	1.00	
26*	A	0.0050			0.70	0.70		0.30		0.30	0.0150	3.0	0.30	0.10	0.40	1.010	0.80	5.00	

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- 16 -

27*	D	0.0150		0.90	0.90	0.10		0.10	0.0300	2.0	0.20	0.20	0.40	1.010	1.20	1.00
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* Samples with an asterisk are those out of the scope of the invention.
 ** Based on the main component
 *** Per 100 parts by weight of (main component + MgO)

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- 17 -

The resulting mixture was kneaded in a ball mill in a wet process together with a polyvinyl butyral-based binder and an organic solvent, such as ethanol, to prepare a ceramic slurry. The slurry was shaped into a 11 μm thick rectangular green sheet by means of a doctor blade. A conductive paste mainly comprising nickel was screen printed on the ceramic green sheet to form a conductive paste layer one end of which reached the end of the green sheet.

A plurality of the ceramic green sheets were piled up in such a manner that the every other ceramic green sheet had its end with the internal electrode exposed arranged on one side of the resulting laminate. The laminate was heated at 350°C in a nitrogen atmosphere to burn the binder and then calcined at a temperature shown in Table 3 for 2 hours in a reducing atmosphere of $\text{H}_2\text{-N}_2\text{-H}_2\text{O}$ gas having an oxygen partial pressure of 10^9 to 10^{12} MPa to obtain a ceramic laminate.

The surface of the resulting ceramic laminate was observed under a scanning electron microscope [of] at 1500 magnifications to measure the grain size.

A silver paste containing $\text{B}_2\text{O}_3\text{-Li}_2\text{O-SiO}_2\text{-BaO}$ -based glass [frits] frit was applied onto both sides of the ceramic laminate where the internal electrodes were exposed and baked at 600°C in a nitrogen atmosphere to form an external electrode electrically connected to the internal electrodes.

The thus prepared monolithic ceramic capacitor had a width of 1.6 mm, a length of 3.2 mm[,] and a thickness of 1.2 mm. Each dielectric ceramic layer between two internal electrode layers had a thickness of 8 μm . The number of effective dielectric ceramic layers

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- 18 -

was 19. The area of the opposing electrodes was 2.1 mm² per side.

The electric characteristics of the condenser were measured. The capacitance (C) and the dielectric loss (tan δ) were measured with an automatic bridge type meter at 1 kHz, 1 Vrms[,] and 25°C. From the capacitance was calculated the dielectric constant (ϵ). The insulation resistance (R) was measured by applying a direct voltage of 16 V for 2 minutes at 25°C and 125°C with an insulation resistance tester, and [a] the product of the capacitance (C) and the insulation resistance (R), i.e., CR product, was obtained.

Further, capacitance was measured at [a] varying [temperature] temperatures to determine [a] the percentage [of a] difference between capacitances measured at -25°C or 85°C and 20°C to the capacitance at 20°C (percentage change: $\Delta C/C_{20^\circ C}$), a percentage of a difference between capacitances measured at -55°C or 125°C and 25°C to the capacitance at 25°C (percentage change: $[C/C_{25^\circ C}]\Delta C/C_{25^\circ C}$), and the maximum absolute percentage change in capacitance measured in a temperature range of from -55 to 125°C ($|C|_{\max}$).

The duration of the condenser was evaluated by a high-temperature loading test. A direct voltage of 100 V was applied to each of 36 condensers per sample at 150°C, and the insulation resistance (R) was measured with time. The time when the insulation resistance fell to 10⁶ Ω or lower was taken as [a] the life duration [of life], and an average duration of life was obtained for each sample.

Furthermore, the condenser was subjected to a high-humidity loading test[,] in which a direct voltage of 16 V was applied to each of 72 condensers per sample

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- 19 -

5 at 121°C, 2 atm[,] and 100% RH, and the insulation resistance (R) was measured with time. The number of rejects whose insulation resistance (R) fell to $10^6 \Omega$ or lower before 250 hours from the start of the test was counted.

The results of the above measurements are shown in Table 3 below.

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- 20 -

Table 3

Sample No.	Calcining Temp. (°C)	Dielectric Constant (ε)	Dielectric Loss [(tan δ)(%) tan δ(%)	Percentage Change in Capacitance ΔC/C20°C (%)			CR Product (25°C) (MΩ·μF)	CR Product (125°C) (MΩ·μF)	Average Duration of Life (hr)	Reject Rate in High-Humidity Loading Test	Grain Size (μm)
				-25°	85°	125°C					
1*	1300	2780	3.0	-4.9	17.4	-10.9	8210	16V	4	0.72	0.79
2*	1300			unmeasurable due to transformation into a semiconductor							2.7
3*	1300	3380	2.1	0.0	-7.8	-0.6	6350	1620	311	0.72	0.74
4*	1280			unmeasurable due to transformation into a semiconductor							2.1
5*	1280	3330	2.3	-0.3	-9.7	-0.7	4120	710	102	0.72	0.73
6*	1280	3380	2.1	0.7	-13.6	0.9	5310	1310	303	0.72	0.74
7*	1360			unmeasurable due to undercalcination							0.61
8	12801	3360	2.2	0.0	-10.0	-0.2	7170	4820	325	0.72	0.74
9	1300	3110	1.6	-0.1	-7.9	-0.2	6140	2420	437	0.72	0.68
10	1300	3300	1.8	0.2	-7.7	-0.6	7600	3150	426	0.72	0.73
11	1300	3010	1.4	-0.1	-7.0	-0.8	6680	2660	389	0.72	0.60
12	1300	3260	1.7	0.1	-8.3	-0.2	6140	2440	482	0.72	0.76
13	1280	3080	1.5	-0.1	-7.1	-0.5	7850	3080	321	0.72	0.68
14	1300	3170	1.7	-0.3	-6.0	-1.3	6340	2450	419	0.72	0.69

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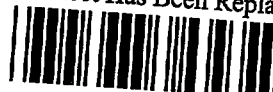
- 21 -

Table 3 - Cont'd.

Sample No.	Calcining Temp. (°C)	Dielectric Constant (ε)	Dielectric Loss {(tanδ)(%)}	Percentage Change in Capacitance ΔC/C20°C (%)			Percentage Change in Capacitance ΔC/C25°C (%)		CR Product (25°C) (MΩ·μF)	CR Product (125°C) (MΩ·μF)	Average Duration of Life (hr)	Reject Rate in High-Humidity Loading Test	Grain Size (μm)
				-25°	85°		55°C	125°C					
15	1300	3300	2.0	0.1	-8.7		0.5	-9.9	6900	16V	379	0/72	0.72
16	1280	3080	1.3	0.8	-7.3		0.1	-12.1	6980	2810	370	0/72	0.71
17*	1360	2260	2.0	0.2	-7.7		-0.5	-9.0	4990	1560	284	12/72	0.64
18*	1300	3010	2.0	0.1	-9.8		-0.6	-16.0	5880	890	52	0/72	0.69
19*	1300	3560	2.3	1.2	-13.0		0.9	-19.5	6150	1430	298	0/72	0.76
20*	1300	3340	2.2	1.6	-15.9		0.9	-18.0	6700	2030	373	0/72	0.72
21*	1300	3200	1.7	0.1	-9.3		-0.1	-11.3	4580	720	173	0/72	0.71
22*	1300	3100	1.5	-0.3	-7.5		-1.2	-8.5	4650	860	192	0/72	0.69
23*	1280	3180	1.8	0.9	-9.7		-0.1	-12.1	4050	690	183	0/72	0.70
24*	1360								unmeasurable due to undercalcination				
25*	1360	2570	1.1	-0.1	-6.0		-1.0	-7.2	5070	1600	353	48/72	0.66
26*	1260	2310	1.8	0.9	-13.1		0.6	-19.3	5120	2330	401	0/72	0.64
27*	1280	2370	1.6	0.4	-5.3		0.7	-6.1	6810	2490	498	0/72	0.64

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- 22 -

Samples with an asterisk are those out of the scope of the invention.

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- 23 -

As is apparent from Tables 1 through 3, the monolithic ceramic capacitors according to the present invention have a dielectric constant (ϵ) of not smaller than 3000 and a dielectric loss ($\tan \delta$) of not more than 2.5%, and their percentage change in capacitance with temperature satisfies the B characteristics standard (JIS) between -25°C and 85°C and the X7R characteristics standard (EIA) between -55°C and 125°C. The insulation resistance at 25°C or 125°C, as expressed in terms of CR product, is as high as 6000 MΩ·μF or more or 2000 MΩ·μF or more, respectively. The average duration of life is as long as 300 hours or longer. The ceramic material used in these condensers can be calcined at relatively low temperatures of 1300°C or lower. The grain size of the ceramic is not greater than 1 μm.

In the composition represented by formula $(1-\alpha-\beta)\{BaO\}_m \cdot TiO_2 + \alpha\{(1-x)M_2O_3 + xRe_2O_3\} + \beta(Mn_{1-y}Ni_yCo_z)O$ (wherein M_2O_3 and Re_2O_3 are as defined above), α should range from about 0.0025 to 0.025 [If α representing] and preferably about 0.006-0.015. If α , the amount of $(M_2O_3+Re_2O_3)_L$ is less than about 0.0025 as in sample 1, the dielectric constant ϵ is lower than 3000, the dielectric loss ($\tan \delta$) exceeds 2.5%, the capacity considerably varies with temperature change, and the average duration of life is extremely short.

If α exceeds about 0.025 as in sample 17, the dielectric constant does not exceed 3000, the insulation resistance at 25°C and 125°C is reduced, the average duration of life is short, a high calcining temperature is required, and rejects occur in a high-humidity loading test.

In the above formula, β representing the amount of (Mn, Ni, Co) should range from about 0.0025 to 0.05

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- 24 -

5 and preferably about 0.005-0.03. If β is less than about 0.0025, the dielectric ceramic is reduced upon calcination in a reducing atmosphere and changes into a semiconductor having a reduced insulation resistance as is observed with sample 2.

If β exceeds about 0.05, the insulation resistance is low, the average duration of life is short, and the variation in capacity with temperature change is large as is observed with sample 18.

10 The ratio β/α representing the ratio of the amount of (Mn, Ni, Co) to the amount of ($M_2O_3 + Re_2O_3$) should be about 4 or less and preferably about 3 or less. If it exceeds about 4, the variation in capacity with temperature change is large, the insulation resistance at
15 125°C is lower than 2000 M $\Omega \cdot \mu F$ (in terms of CR product), and the average duration of life is shorter than 300 hours as with sample 19.

x should be more than 0 and not more than about 0.50 and preferably about 0.1-0.3. If x is 0 as in
20 sample 3, the insulation resistance is less than 2000 M $\Omega \cdot \mu F$ (CR product). If x exceeds about 0.5 as in sample 20, the variation in capacity with temperature change is too large to satisfy the B characteristics specified in JIS and the X7R characteristics specified by
25 EIA standards.

m representing the molar ratio of barium titanate should be more than about 1.000 and not more than about 1.035 and preferably about 1.005-1.02. If it
30 is less than about 1.000 the dielectric ceramic material is transformed into a semiconductor as is observed with sample 4. If it is 1.000 as in sample 5, the insulation resistance is low, and the average duration of life is shorter than 300 hours. If the molar ratio m exceeds

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- 25 -

about 1.035, the calcination properties are extremely poor as is observed with sample 24.

$y+z$ in the above formula should be 0 [or more and] to less than about 1.0, preferably about 0.1-0.5.

5 If $y+z$ is 1.00 (i.e., Mn is absent) as in samples 21, 22 and 23, the insulation resistance is reduced, and the average duration of life is shorter than 300 hours.

10 The amount of magnesium oxide as a secondary component should range from about 0.5 to 5.0 mol in terms of MgO per 100 mol of the main component and preferably about 0.8-1.5. If it is less than about 0.5 mol as in sample 6, the insulation resistance is reduced, and the variation in capacity with temperature change becomes high. On the other hand, if the amount of MgO exceeds
15 about 5 mol, the calcining temperature must be increased, and the reject rate in a high-humidity loading test is extremely high as with the case of sample 25.

20 The amount of the $\text{SiO}_2\text{-TiO}_2\text{-MO}$ -based oxide glass should be in a range of from about 0.2 to 3.0 parts by weight per 100 parts by weight of the total weight of the main component and the secondary component, MgO, and preferably about 1-1.5. If it is less than about 0.2 part as in sample 7, the ceramic material suffers from undercalcination. If it exceeds about 3.0 parts as
25 in sample 26, the dielectric constant is low, the insulation resistance at 25°C does not exceed 6000 $\text{M}\Omega \cdot \mu\text{F}$ (CR product), and the variation in capacity with temperature change becomes larger.

30 The content of alkali metal oxide impurities in barium titanate should be about 0.02% by weight or less and preferably about 0.012. If it exceeds about 0.02% as in sample 27, reduction in dielectric constant results.

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- 26 -

EXAMPLE 2

SiO₂-TiO₂-MO-based oxide [glass] glasses having an average particle size of not greater than 1 μ m and [a] the composition shown in Table 4 below were prepared by heating a raw material mixture at 1200 to 1500°C in the same manner as in Example 1. A hundred moles of a main component represented by compositional formula:
97.5{BaO}_{1.010}·TiO₂ + 0.8Y₂O₃ + 0.2Gd₂O₃ + 1.5(Mn_{0.4}Ni_{0.2}Co_{0.4})O (molar ratio) in which barium titanate A shown in Table 1 was used, 1.0 mol of MgO, and 1.0% by weight, based on the total weight of the main component and MgO, of the above oxide glass were compounded to prepare a ceramic material.

** 1 A monolithic ceramic capacitor was produced in the same manner as in Example 1, except for using the above prepared ceramic material. The electrical characteristics of the resulting condenser were evaluated in the same manner as in Example 1. The results obtained are shown in Table 5 below.

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- 27 -

Table 4													
Sample No.	Amount of Oxide Glass Added (wt %)	Components of Oxide Glass											
		Main Components (mol %)										Additive Component (%)	
		MO											
		SiO ₂	TiO ₂	BaO	CaO	SrO	MgO	ZnO	MnO	Total	Al ₂ O ₃	ZrO ₂	
101	1.0	85	1	-	-	-	-	4	9	14	-	-	
102	1.0	35	51	-	10	-	-	-	4	14	-	-	
103	1.0	30	20	-	30	-	15	4	1	50	-	-	
104	1.0	39	1	20	20	2	-	13	5	60	-	-	
105	1.0	70	10	5	5	-	-	10	-	20	-	-	
106	1.0	45	10	-	-	-	-	15	30	45	-	-	
107	1.0	50	20	10	10	3	7	-	-	30	-	-	
108	1.0	50	30	-	16	-	-	-	4	20	-	-	
109	1.0	35	30	25	10	-	-	-	-	35	-	-	
110	1.0	40	40	10	-	-	-	5	5	20	-	-	
111	1.0	45	22	3	30	-	-	-	-	33	15	-	
112	1.0	45	22	3	30	-	-	-	-	33	10	5	
113*	1.0	65	25	5	5	-	-	-	-	10	-	-	
114*	1.0	25	40	15	-	10	-	5	5	35	-	-	
115*	1.0	30	10	30	25	-	-	5	-	60	-	-	

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- 28 -

Table 4 - Cont'd.												
Components of Oxide Glass												
Sample No.	Amount of Oxide Glass Added (wt %)	Main Components (mol %)										Additive Component (%)
		MO								Total	Al ₂ O ₃	ZrO ₂
		SiO ₂	TiO ₂	BaO	CaO	SrO	MgO	ZnO	MnO			
116*	1.0	50	0	35	15	-	-	-	-	50	-	-
117*	1.0	45	22	30	-	-	3	-	-	33	25	-
118*	1.0	45	22	30	-	3	-	-	-	33	-	15
119*	1.0	30	66	10	-	-	-	-	-	10	-	-

Samples with an asterisk are those out of the scope of the invention.

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- 29 -

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Table 5														
Sample No.	Calcining Temp. (°C)	Dielectric Constant (ε)	Dielectric Loss [(tanδ)(%) K(tan δ)(%)	Percentage Change in Capacitance ΔC/C20°C (%)		Percentage Change in Capacitance ΔC/C25°C (%)			CR Product (25°C) (MΩ·μF)	CR Product (125°C) (MΩ·μF)	Average Duration of Life (hr)	Reject Rate in High-Humidity Loading Test	Grain Size (μm)	
				-25°	-85°	55°C	125°C	max						
101	1300	3080	1.9	-1.2	-7.2	-2.3	-8.0	8.0	6520	2420	412	0/72	0.71	
102	1300	3330	2.1	-1.0	-7.1	-1.6	-7.4	7.4	6120	2160	356	0/72	0.70	
103	1300	3260	1.8	-0.9	-8.0	-0.4	-9.9	9.9	6830	2710	379	0/72	0.70	
104	1300	3260	1.7	-1.4	-6.5	-1.7	-7.2	7.2	6580	2500	403	0/72	0.70	
105	1280	3190	2.1	-0.9	-7.5	-1.5	-8.1	8.1	6470	2520	388	0/72	0.70	
106	1280	3250	1.8	-1.3	-6.3	-1.6	-7.4	7.4	6510	2520	358	0/72	0.71	
107	1300	3270	1.8	-1.2	-7.9	-1.6	-8.9	8.9	6330	2320	392	0/72	0.71	
108	1280	3150	1.5	-0.5	-8.6	-0.1	-10.7	10.7	6760	2610	416	0/72	0.70	
109	1280	3410	2.2	-1.1	-7.1	-1.6	-7.4	7.4	6540	2470	491	0/72	0.72	
110	1280	3300	2.0	-0.3	-9.3	0.0	-11.3	11.3	6140	2190	338	0/72	0.71	
111	1300	3110	1.9	-0.7	-7.8	-1.2	-8.8	8.8	7970	3460	590	0/72	0.70	
112	1300	3070	1.8	-0.6	-8.4	-0.8	-12.7	12.7	7410	3380	585	0/72	0.71	
113*	1360	2660	2.5	-2.1	-2.3	-2.8	1.5	3.0	4920	1710	36	53/72	0.66	

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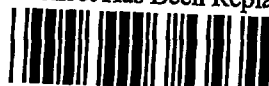
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114*	1360	unmeasurable due to undercalcination											0.61	
Table 5 - Cont'd.														
Sample No.	Calcining Temp. (°C)	Dielectric Constant (ε)	Dielectric Loss [(tanδ)(%) 1(tan δ)(%)	Percentage Change in Capacitance ΔC/C20°C (%)		Percentage Change in Capacitance ΔC/C25°C (%)		CR Product (25°C) (MΩ·μF)	CR Product (125°C) (MΩ·μF)	Average Duration of Life (hr)	Reject Rate in High-Humidity Loading Test	Grain Size (μm)		
				-25°	85°	55°C	125°C						max	
				unmeasurable due to undercalcination										
115*	1360			-1.2	-7.5	-1.2	-9.6	9.6	6440	2280	363	72/72	0.70	
116*	1360	3290	2.2	-1.2	-7.5	-1.2	-9.6	9.6	6440	2280	363	72/72	0.70	
117*	1360			unmeasurable due to undercalcination										0.61
118*	1360			unmeasurable due to undercalcination										0.61
119*	1360			unmeasurable due to undercalcination										0.61

Samples with an asterisk are those out of the scope of the invention.

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- 31 -

As is apparent from Tables 4 and 5, the monolithic ceramic capacitors constituted by the dielectric ceramic layers containing SiO_2 - TiO_2 -MO-based oxide glass according to the present invention exhibit a high dielectric constant (ϵ) of 3000 or more, a dielectric loss ($\tan \delta$) of not more than 2.5%, and their percentage change in capacitance with temperature satisfies the B characteristics standard (JIS) between -25°C and 85°C and the X7R characteristics standard (EIA) between -55°C and 125°C. The insulation resistance at 25°C or 125°C, as expressed in terms of CR product, is as high as 6000 $\text{M}\Omega \cdot \mu\text{F}$ or more or 2000 $\text{M}\Omega \cdot \mu\text{F}$ or more, respectively. The average duration of life is as long as 300 hours or longer. No rejects [was] were observed in the high-humidity loading test.

To the contrary, samples 113 to 116 and 119 showed undercalcination or developed rejects in the high-humidity loading test. That is, when the composition of SiO_2 - TiO_2 -MO-based oxide glass is plotted on a triangular diagram of (SiO_2 , TiO_2 , MO) (wherein MO is as defined above), the composition of the oxide glass used in these samples is not in the area surrounded by, or not on, four straight lines connecting four points: A (85,1,14), B (35,51,14), C (30,20,50), and D (39,1,60) (unit: mol%).

As is understood from the results of samples 111 and 112, addition of Al_2O_3 or ZrO_2 to the SiO_2 - TiO_2 -MO-based oxide glass is effective to provide a monolithic ceramic capacitor having an insulation resistance (CR product) of not lower than 7000 $\text{M}\Omega \cdot \mu\text{F}$ at 25°C and not lower than 3000 $\text{M}\Omega \cdot \mu\text{F}$ at 125°C. Note that addition of more than 15 parts by weight of Al_2O_3 or more than 5 parts by weight of ZrO_2 , per 100 parts by weight of the SiO_2 -

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- 32 -

TiO₂-MO-based oxide glass results in extreme reduction in sintering properties.

5 While the barium titanate powder used in the foregoing Examples is one prepared by an oxalic acid process, barium titanate powder prepared by an alkoxide process or a hydrothermal process can be used as well. In some cases, use of barium titanate powder prepared by an alkoxide process or a hydrothermal process can bring about better characteristics than demonstrated in the
10 above Examples.

Further, while oxide powders, such as scandium oxide, yttrium oxide, gadolinium oxide, terbium oxide, dysprosium oxide, manganese oxide, cobalt oxide, nickel oxide[,] and magnesium oxide, were used as raw materials,
15 the raw materials for the dielectric ceramic layers are not limited to these oxides. For example, a solution of an alkoxide or an organometallic compound of each metal element can be used as well as long as the resulting ceramic layer has the composition according to the
20 present invention.

While the invention has been described in detail and with reference to specific embodiments thereof, it will be apparent to one skilled in the art that various changes and modifications can be made
25 therein without departing from the spirit and scope thereof.

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- 33 -

WHAT IS CLAIMED IS:

1. A monolithic ceramic capacitor [having]
comprising a laminate of a plurality of dielectric
ceramic layers, [a plurality of] at least internal
electrodes [each formed] between [every two] adjacent
5 dielectric ceramic layers in such a manner that one end
of each internal electrode is exposed at [one end]
different ends of the dielectric ceramic layer
alternately, and a pair of external electrodes each
electrically connected to [the plurality of] different
10 exposed internal electrodes [on each side of the
laminate], in which said dielectric ceramic [layer
comprises] layers comprise (a) barium titanate having an
alkali metal oxide impurity content of not more than
about 0.02% by weight, (b) at least one member selected
15 from the group consisting of scandium oxide and yttrium
oxide, (c) at least one member selected from the group
consisting of gadolinium oxide, terbium oxide[,] and
dysprosium oxide, (d) manganese oxide, (e) cobalt
oxide[,] and (f) nickel oxide, and is [made up of] a
20 material containing

(1) 100 mol of a main component represented by
the compositional formula:



wherein M_2O_3 represents at least one member selected from
25 the group consisting of Sc_2O_3 and Y_2O_3 ; Re_2O_3 represents at
least one member selected from the group consisting of
 Gd_2O_3 , Tb_2O_3 [,] and Dy_2O_3 ; $0.0025 \leq \alpha \leq 0.025$; $0.0025 \leq \beta \leq 0.05$;
 $\beta/\alpha \leq 4$; $0 < x \leq 0.50$; $[0 \leq y \leq 1.0; 0 \leq z \leq 1.0]$ $0 \leq y \leq 1.0; 0 \leq z \leq 1.0$;
 $0 \leq y + z < 1.0$; and $1.000 < m \leq 1.035$,

30 (2) about 0.5 to 5.0 mol, in terms of MgO, of
magnesium oxide [as a secondary component,] and

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- 34 -

(3) about 0.2 to 3.0 parts by weight, per
100 parts by weight of the total weight of said main
component (1) and said [secondary component] magnesium
oxide (2), of SiO_2 - TiO_2 -MO-based oxide glass, wherein MO
represents at least one member selected from the group
consisting of BaO, CaO, SrO, MgO, ZnO[,] and MnO[,] and
said internal electrodes are made up of nickel or a
nickel alloy].

2. A monolithic ceramic capacitor according
to claim 1, wherein the internal electrodes are of nickel
or a nickel alloy.

3. A monolithic ceramic capacitor according
to claim 2, wherein the alkali metal oxide impurity
content of not more than about 0.012% by weight; M_2O_3
represents Y_2O_3 ; Re_2O_3 comprises Dy_2O_3 ; $0.006 \leq \alpha \leq 0.015$;
 $0.005 \leq \beta \leq 0.03$; $\beta/\alpha \leq 3$; $0.1 \leq x \leq 0.3$; $0.1 \leq v \leq 0.2$; $0.1 \leq z \leq 0.5$;
 $0.1 \leq y + z \leq 0.5$; and $1.005 \leq m \leq 1.02$; the amount of MgO is about
0.8-1.5 mol; the amount of glass is about 1-1.5 parts;
and MO comprises CaO.

4. A monolithic ceramic capacitor according
to claim 3, wherein the composition of said SiO_2 - TiO_2 -MO-
based oxide glass is, when plotted on a triangular mol%
diagram of (SiO_2 , TiO_2 , MO) [, wherein MO is at least one
member selected from the group consisting of BaO, CaO,
SrO, MgO, ZnO, and MnO,] in the area surrounded by, or
on, four straight lines connecting four points: A
(85,1,14), B (35,51,14), C (30,20,50), and D (39,1,60)
[(unit: mol%)] and contains at least one of Al_2O_3 and ZrO_2
in a total amount of not more than 15 parts by weight per
100 parts by weight of the (SiO_2 , TiO_2 , MO) component,

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provided that the amount of ZrO_2 is not more than 5 parts by weight.

[3] 5. A monolithic ceramic capacitor according to claim [1] 4, wherein said external electrodes [are each made up of] comprise a sintered layer of an electrically conductive metal powder or an electrically conductive metal powder containing glass [frits] frit.

[4] 6. A monolithic ceramic capacitor according to claim [1] 4, wherein said external electrodes [are each composed of] comprise a first layer made of a sintered layer of an electrically conductive metal powder or an electrically conductive metal layer containing glass [frits] frit and a second layer [that is formed] of plating on said first layer [by plating].

7. A monolithic ceramic capacitor according to claim 1, wherein the alkali metal oxide impurity content of not more than about 0.012% by weight; M_2O_3 represents Y_2O_3 ; Re_2O_3 comprises Dy_2O_3 ; $0.006 \leq \alpha \leq 0.015$; $0.005 \leq \beta \leq 0.03$; $\beta/\alpha \leq 3$; $0.1 \leq x \leq 0.3$; $0.1 \leq y \leq 0.2$; $0.1 \leq z \leq 0.5$; $0.1 \leq y+z \leq 0.5$; and $1.005 \leq m \leq 1.02$; the amount of MgO is about 0.8-1.5 mol; the amount of glass is about 1-1.5 parts; and MO comprises CaO .

8. A monolithic ceramic capacitor according to claim 7, wherein the composition of said SiO_2 - TiO_2 - MO -based oxide glass is, when plotted on a triangular mol% diagram of (SiO_2 , TiO_2 , MO) in the area surrounded by, or on, four straight lines connecting four points: A (85,1,14), B (35,51,14), C (30,20,50), and D (39,1,60)

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15 and contains at least one of Al_2O_3 and ZrO_2 in a total
amount of not more than 15 parts by weight per 100 parts
by weight of the (SiO_2 , TiO_2 , MO) component, provided that
the amount of ZrO_2 is not more than 5 parts by weight.

5 9. A monolithic ceramic capacitor according
to claim 8, wherein said external electrodes comprise a
sintered layer of an electrically conductive metal powder
or an electrically conductive metal powder containing
glass frit.

5 10. A monolithic ceramic capacitor according
to claim 8, wherein said external electrodes comprise a
first layer made of a sintered layer of an electrically
conductive metal powder or an electrically conductive
metal layer containing glass frit and a second layer of
plating on said first layer.

11. A monolithic ceramic capacitor according
to claim 1, wherein the composition of said SiO_2 - TiO_2 - MO -
based oxide glass is, when plotted on a triangular mol%
diagram of (SiO_2 , TiO_2 , MO) in the area surrounded by, or
on, four straight lines connecting four points: A
(85,1,14), B (35,51,14), C (30,20,50), and D (39,1,60)
and contains at least one of Al_2O_3 and ZrO_2 in a total
amount of not more than 15 parts by weight per 100 parts
by weight of the (SiO_2 , TiO_2 , MO) component, provided that
the amount of ZrO_2 is not more than 5 parts by weight.

12. A monolithic ceramic capacitor according
to claim 11, wherein said external electrodes comprise a
sintered layer of an electrically conductive metal powder

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5 or an electrically conductive metal powder containing glass frit.

5 13. A monolithic ceramic capacitor according to claim 11, wherein said external electrodes comprise a first layer made of a sintered layer of an electrically conductive metal powder or an electrically conductive metal layer containing glass frit and a second layer of plating on said first layer.

14. A monolithic ceramic capacitor according to claim 1, wherein said external electrodes comprise a sintered layer of an electrically conductive metal powder or an electrically conductive metal powder containing glass frit.

5 15. A monolithic ceramic capacitor according to claim 1, wherein said external electrodes comprise a first layer made of a sintered layer of an electrically conductive metal powder or an electrically conductive metal layer containing glass frit and a second layer of plating on said first layer.



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MONOLITHIC CERAMIC CAPACITOR

ABSTRACT OF THE DISCLOSURE

A monolithic ceramic capacitor having a plurality of dielectric ceramic layers, [a plurality of] internal electrodes, and [a pair of] external electrodes [each] electrically connected to the internal electrode, wherein the dielectric ceramic [layer comprises] layers comprise (a) barium titanate having an alkali metal oxide impurity content of not more than about 0.02% by weight, (b) [at least one member selected from the group consisting of] scandium oxide [and] and/or yttrium oxide, (c) [at least one member selected from the group consisting of] gadolinium oxide, terbium oxide[, and] and/or dysprosium oxide, (d) manganese oxide, (e) cobalt oxide, and (f) nickel oxide, and is [made up of] a material containing (1) 100 [mol of a main component] mols represented by the compositional formula:

$$(1-\alpha-\beta) \{ \text{BaO} \}_m \cdot \text{TiO}_2 + \alpha \{ (1-x) \text{M}_2\text{O}_3 + x \text{Re}_2\text{O}_3 \} + \beta (\text{Mn}_{1-y-z} \text{Ni}_y \text{Co}_z) \text{O}$$

wherein M_2O_3 represents [at least one member selected from the group consisting of Sc_2O_3 and Y_2O_3 ; Re_2O_3 represents at least one member selected from the group consisting of Gd_2O_3 , Tb_2O_3 , and Dy_2O_3 ; $0.0025 \leq \alpha \leq 0.025$] said (b); Re_2O_3 represents said (c); $0.0025 \leq \beta \leq 0.05$; $\beta/\alpha \leq 4$; $0 < x \leq 0.50$; $0 \leq y \leq 1.0$; $0 \leq z \leq 1.0$; $0 \leq y+z \leq 1.0$; and $1.000 < m \leq 1.035$, (2) about 0.5 to 5.0 mol, in terms of MgO, of magnesium oxide [as a secondary component,] and (3) about 0.2 to 3.0 parts by weight, per 100 [parts by weight of the total weight of said main component (1) and said secondary component] pph of components (1) and (2), of SiO_2 - TiO_2 -MO-based oxide glass (wherein MO represents at least one member selected from the group consisting of BaO, CaO, SrO, MgO, ZnO, and

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MnO) [, and said], Said internal electrodes [are made up
of] can be nickel or a nickel alloy[, is disclosed].

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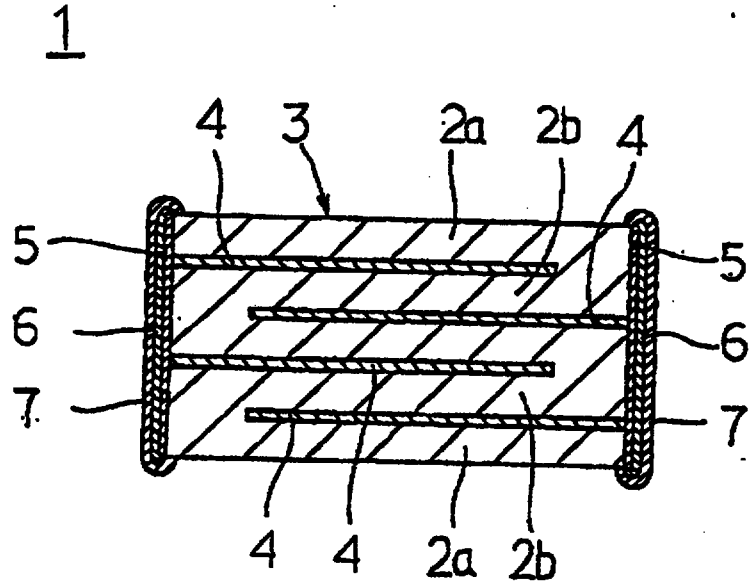
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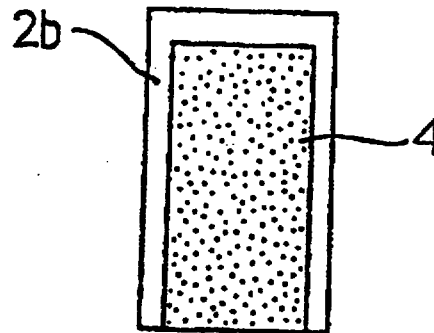
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【図1】 Fig.1

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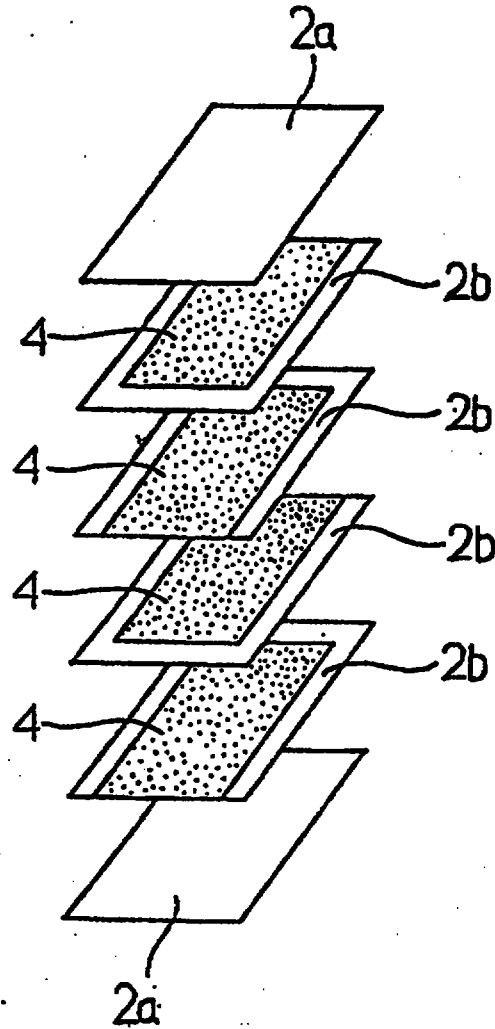
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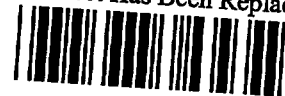
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コード 【図3】 Fig.3

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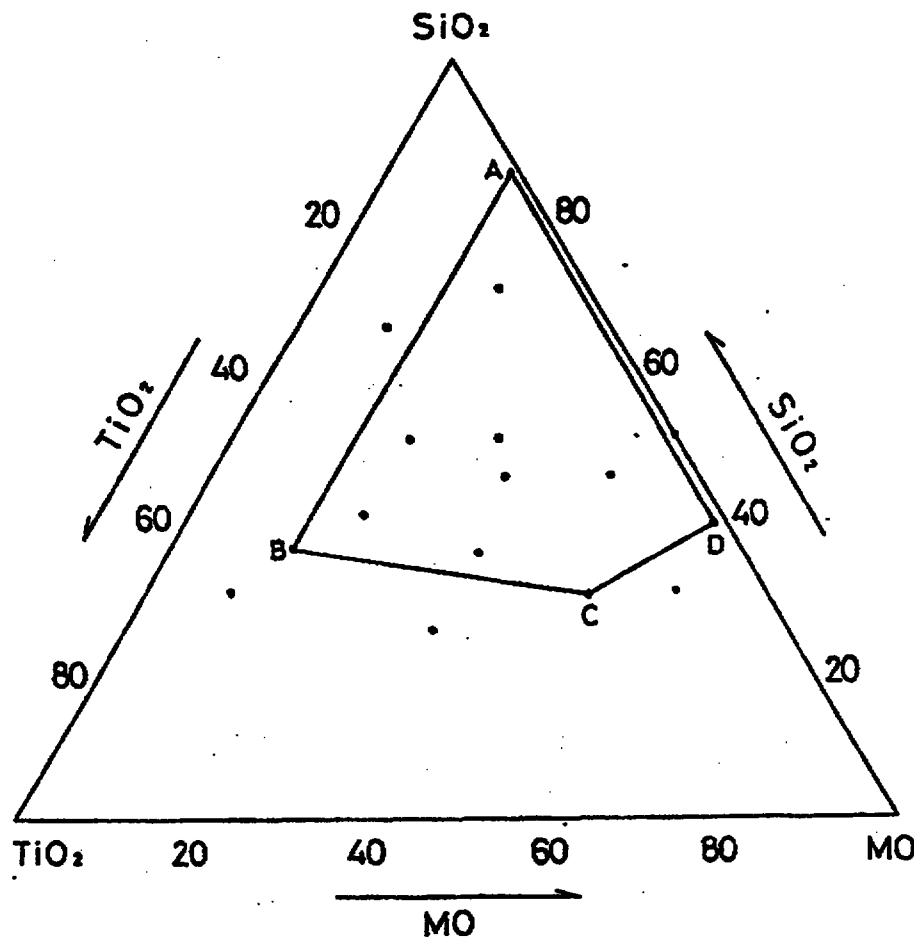
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コード 【図4】 Fig. 4

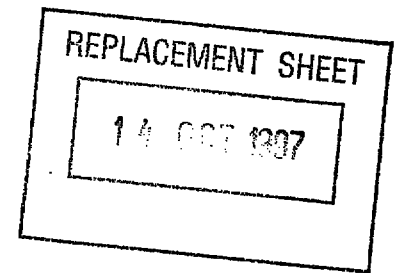
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MONOLITHIC CERAMIC CAPACITOR

FIELD OF THE INVENTION

This invention relates to a ceramic capacitor, more particularly a monolithic ceramic capacitor having internal electrodes made of nickel or a nickel alloy.

BACKGROUND OF THE INVENTION

A monolithic ceramic capacitor is generally produced according to the following procedures. Dielectric ceramic layers in sheet form [each] having applied thereon an electrode material [serving] to serve as an internal electrode are prepared. A ceramic material mainly comprising, e.g., BaTiO_3 , is used as a dielectric ceramic layer. A plurality of the dielectric ceramic layers with the electrode material are piled up and press-bonded under heat into one body. The resulting laminate is calcined [in a natural atmosphere] at 1250 to 1350°C to obtain a ceramic laminate having internal electrodes. An external electrode is baked onto both sides of the ceramic laminate to make an electrical connection to the internal electrodes [to] and obtain a monolithic ceramic capacitor.

The material for the internal electrodes are required to satisfy the following conditions:

1. To have a melting point at or above the calcining temperature of the ceramic laminate because the internal electrodes and the ceramic laminate are calcined simultaneously.

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14 OCT 1987

- 2 -

2. To be [insusceptible] resistant to oxidation in a high-temperature oxidative atmosphere and be unreactive with the dielectric ceramic layer.

Noble metals, such as platinum, gold, palladium[,] and a silver-palladium alloy, have been used as an electrode material satisfying these requirements. While excellent in performance, these electrode materials are so expensive that the proportion of the electrode material cost reaches 30 to 70% of [all] the entire material cost, which has been the greatest factor of increasing the production cost of monolithic ceramic capacitors.

In addition to noble metals, base metals, such as Ni, Fe, Co, W[,] and Mo, also have a high melting point. However, these base metals are readily oxidized in a high-temperature oxidative atmosphere, [failing] causing them to fail to perform [the] their function as an electrode. Therefore, calcination of the base metal together with dielectric ceramic layers must be carried out in a neutral or reducing atmosphere before [it] they can be used as an internal electrode of a monolithic ceramic capacitor. However, the problem is that a conventional dielectric ceramic material undergoes vigorous reduction into a semiconductor if calcined in a neutral or reducing atmosphere.

Dielectric ceramic materials which have been proposed in order to solve the above problem include a dielectric ceramic material comprising a barium titanate solid solution having a barium site to titanium site ratio in excess of a stoichiometric one (see JP-B-57-42588, the term "JP-B" as used herein means an "examined published Japanese patent application") and a dielectric ceramic material comprising a barium titanate solid

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14 OCT 1987

solution having incorporated therein an oxide of a rare earth metal, such as La, Nd, Sm, Dy or Y (see JP-A-61-101459, the term "JP-A" as used herein means an "unexamined published Japanese patent application").

On the other hand, dielectric ceramic materials whose dielectric constant has reduced temperature dependence, such as [a] $\text{BaTiO}_3\text{-CaZrO}_3\text{-MnO-MgO}$ system (see JP-A-62-256422) and [a] $\text{BaTiO}_3\text{-(Mg, Zn, Sr or Ca)O-B}_2\text{O}_3\text{-SiO}_2$ system (see JP-B-61-14611), have also been proposed.

Use of these dielectric ceramic materials have made it possible to obtain a ceramic laminate that is not transformed into a semiconductor even when calcined in a reducing atmosphere, thereby making it feasible to produce a monolithic ceramic capacitor in which a base metal, such as nickel, is used as an internal electrode.

In recent years, size reduction of electronic components has [been] accelerated rapidly [with] in the development of electronics. Monolithic ceramic capacitors have also showed a remarkable tendency to reduction in size and increase in capacity. There has thus been an increasing demand for a dielectric ceramic material which has a high dielectric constant, shows reduced variation in dielectric constant with temperature change, and is thereby highly reliable.

The dielectric ceramic materials disclosed in JP-B-57-42588 and JP-A-61-101459 exhibit a high dielectric constant but have a large crystal grain size on calcination. When they are applied to a monolithic ceramic capacitor in which each dielectric ceramic layer has [such] a small thickness such as 10 μm or less, the number of crystal grains existing per layer is decreased, resulting in diminished reliability. Besides, these materials undergo considerable variation in dielectric

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constant with temperature change and are not regarded to meet the [demand] demands of the market sufficiently.

The dielectric ceramic material disclosed in JP-A-62-256422, on the other hand, exhibits a relatively high dielectric constant and provides[,] on calcination, a ceramic laminate having a small crystal grain size and [showing] small variation of dielectric constant with temperature change. However, CaZrO_3 and CaTiO_3 produced on calcination tend to form a secondary phase together with MnO , etc., which has made the resulting monolithic ceramic capacitor less reliable in high temperatures.

The dielectric ceramic material disclosed in JP-B-61-14611 exhibits a dielectric constant of 2000 to 2800, which is disadvantageous for achieving size reduction and capacity increase [of] in a monolithic ceramic capacitor. Moreover, the material fails to fulfill the requirement of X7R characteristics specified by EIA (Electronic Industries Association) [Standards] standards that the percentage of change in electrostatic capacity be within a range of $\pm 15\%$ in [a] the temperature range of from -55°C to $+125^\circ\text{C}$.

Although JP-A-5-9066, JP-A-5-9067, and JP-A-5-9068 have proposed ceramic compositions in order to eliminate these problems, the ever-continuing demand for size reduction and capacity increase has been producing a keen demand for dielectric ceramic materials with greater reliability. At the same time, demand for thickness reduction of a ceramic dielectric layer has been getting intenser.

Thus, there has been the necessity for the development of a small-sized and high-capacity monolithic ceramic capacitor having excellent reliability in a high temperature and high humidity environment.

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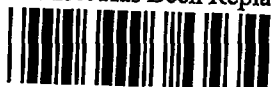
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SUMMARY OF THE INVENTION

An object of the present invention is to provide an economical, small-sized and high-capacity monolithic ceramic capacitor which has a dielectric constant of 3000 or higher and an insulation resistance as high as 6000 MΩ·μF or more at room temperature or 2000 MΩ·μF or more at 125°C, as expressed in terms of the product of capacitance and insulation resistance (CR product), and whose capacity exhibits temperature characteristics satisfying the B characteristics specified by JIS (Japanese Industrial Standards) and the X7R characteristics specified by EIA standards, and which has excellent weathering performance in, for example, loading in high temperature or high humidity.

The present invention provides a monolithic ceramic capacitor having a laminate of a plurality of dielectric ceramic layers, a plurality of internal electrodes each formed between [every] two adjacent dielectric ceramic layers in such a manner that one end of each internal electrode is exposed at one end of the dielectric ceramic layer alternately, and a pair of external electrodes each electrically connected to the plurality of exposed internal electrodes [on each side] of the laminate, in which the dielectric ceramic layer comprises (a) barium titanate having an alkali metal oxide impurity content of not more than about 0.02% by weight, (b) at least one member selected from the group consisting of scandium oxide and yttrium oxide, (c) at least one member selected from the group consisting of gadolinium oxide[,], terbium oxide[,], and dysprosium oxide, (d) manganese oxide, (e) cobalt oxide[,], and (f) nickel oxide, and is made up of a material containing (1)

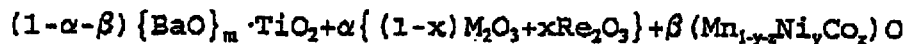
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14 OCT 1987

100 mol of a main component represented by the compositional formula:



wherein M_2O_3 represents at least one member selected from the group consisting of Sc_2O_3 and Y_2O_3 ; Re_2O_3 represents at least one member selected from the group consisting of Gd_2O_3 , Tb_2O_3 , and Dy_2O_3 ; $0.0025 \leq \alpha \leq 0.025$; $0.0025 \leq \beta \leq 0.05$; $\beta/\alpha \leq 4$; $0 < x \leq 0.50$; $0 \leq y \leq 1.0$; $0 \leq z \leq 1.0$; $0 \leq y+z < 1.0$; and $1.000 < m \leq 1.035$, (2) about 0.5 to 5.0 mol, in terms of MgO , of magnesium oxide as a secondary component, and (3) about 0.2 to 3.0 parts by weight, per 100 parts by weight of the total weight of the main component (1) and the secondary component (2), of SiO_2 - TiO_2 - MO -based oxide glass (wherein MO represents at least one member selected from the group consisting of BaO , CaO , SrO , MgO , ZnO , and MnO), and the internal electrodes are made up of nickel or a nickel alloy.

In a preferred embodiment of the monolithic ceramic capacitor of the present invention, the composition of the SiO_2 - TiO_2 - MO -based oxide glass is, when plotted on a triangular diagram of (SiO_2 , TiO_2 , MO) (wherein MO is as defined above), in the area surrounded by, or on, four straight lines connecting four points: A (85,1,14), B (35,51,14), C (30,20,50), and D (39,1,60) (unit: mol%), and contains at least one of Al_2O_3 and ZrO_2 in a total amount of not more than about 15 parts by weight per 100 parts by weight of the (SiO_2 , TiO_2 , MO) component, provided that the amount of ZrO_2 is not more than about 5 parts by weight.

In another preferred embodiment, the external electrode is made up of a sintered layer of an electrically conductive metal powder which may contain

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16 OCT 1987

glass [frits] frit. In a still preferred embodiment, the external electrode is composed of a first layer made of a sintered layer of an electrically conductive metal powder which may contain glass [frits] frit and a second layer that is formed on the first layer by plating.

BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 is a schematic cross section of a monolithic ceramic capacitor according to one embodiment of the present invention.

Fig. 2 is a schematic plan of a ceramic layer with an internal electrode which is used in the monolithic ceramic capacitor of Fig. 1.

Fig. 3 is a perspective exploded view of the ceramic laminate used in the monolithic ceramic capacitor of Fig. 1.

Fig. 4 is a triangular diagram of (SiO_2 , TiO_2 , MO) showing a preferred range of the composition of SiO_2 - TiO_2 -MO-based oxide glass.

DETAILED DESCRIPTION OF THE INVENTION

In the monolithic ceramic capacitor of the present invention, the dielectric ceramic layers are obtained by calcining a dielectric ceramic material comprising (1) (a) barium titanate, (b) at least one of scandium oxide and yttrium oxide, (c) at least one of gadolinium oxide, terbium oxide[,] and dysprosium oxide, (d) manganese oxide, (e) cobalt oxide[,] and (f) nickel oxide at a ratio shown by the above-described compositional formula having incorporated therein (2) magnesium oxide and (3) SiO_2 - TiO_2 -MO-based oxide glass (wherein MO represents at least one member selected from the group consisting of BaO, CaO, SrO, MgO, ZnO, and

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14 OCT 1987

MnO). The dielectric ceramic material can be calcined in a reducing atmosphere without suffering from deterioration of characteristics to provide a highly reliable monolithic ceramic capacitor whose capacity exhibits temperature characteristics satisfying the B characteristics specified by JIS and the X7R characteristics specified by EIA standards, and which exhibits high insulation resistance at room temperature and high temperature.

In the resulting dielectric ceramic laminate, the crystal grains are as small as 1 μm or less so that the grains increase in number per layer. This will secure a sufficient reliability even though the thickness of the dielectric ceramic layer in the laminate is reduced.

The barium titanate constituting the main component (1) contains, as impurities, alkaline earth metal oxides (e.g., SrO and CaO), alkali metal oxides (e.g., Na₂O and K₂O), and other oxides (e.g., Al₂O₃ and SiO₂). Of these impurities, the alkali metal oxides, such as Na₂O and K₂O, have been confirmed to be greatly influential on the electrical characteristics. It was proved that a dielectric constant of not smaller than 3000 can be obtained by using barium titanate having an alkali metal oxide content of not more than about 0.02% by weight and preferably about 0.012% or less.

It has also been found that incorporation of oxide glass mainly comprising SiO₂-TiO₂-MO (wherein MO is at least one member selected from the group consisting of BaO, CaO, SrO, MgO, ZnO, and MnO) into the dielectric ceramic layers brings about improved sintering properties and improved resistance to plating. Further, addition of

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14 OCT 1987

- 9 -

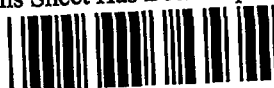
Al_2O_3 and/or ZrO_2 to the oxide glass makes it possible to obtain higher insulation resistance.

Dielectric ceramic layers made from the above-described dielectric ceramic material provide a highly reliable, small-sized, and high-capacity monolithic ceramic capacitor, the capacity of which shows reduced variation with temperature. Use of the dielectric ceramic material makes it feasible to use nickel or a nickel alloy as an internal electrode. It is also possible to use nickel or a nickel alloy in combination with a small amount of ceramic powder.

The external electrode is not particularly limited in composition. For example, it can be a sintered layer of a conductive powder of various metals (e.g., Ag, Pd, Ag-Pd, Cu[,] and Cu alloys) or a sintered layer of a mixture of such a conductive metal powder and glass frits of various kinds (e.g., B_2O_3 - Li_2O - SiO_2 - BaO -based glass frits, B_2O_3 - SiO_2 - BaO -based glass frits, Li_2O - SiO_2 - BaO -based glass frits, B_2O_3 - SiO_2 - ZnO -based glass frits). Ceramic powder may be used in a small proportion with the conductive metal powder (and glass frits). It is preferable that the sintered layer is plated with Ni, Cu, an Ni-Cu alloy, etc. The plated layer may further be plated with solder, tin, etc.

A monolithic ceramic capacitor according to one embodiment of the present invention will be described by referring to the accompanying drawings.

Fig. 1 is a schematic cross section of the monolithic ceramic capacitor. Fig. 2 is a schematic plan of a ceramic layer having an internal electrode used in the monolithic ceramic capacitor of this embodiment. Fig. 3 is a perspective exploded view of the ceramic

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14 OCT 1987

laminate used in the monolithic ceramic capacitor of this embodiment.

As shown in Fig. 1, the monolithic ceramic capacitor 1 is of rectangular chip type having a ceramic laminate 3 composed of a plurality of dielectric ceramic layers 2a and 2b, with an internal electrode 4 being interposed between every two ceramic layers. On each side of the ceramic laminate 3 are formed an external electrode 5, a first plating layer 6 formed by plating with nickel, copper, etc., and a second plating layer 7 formed by plating with solder, tin, etc.

The monolithic ceramic capacitor 1 shown in Fig. 1 can be produced as follows.

(1) A main component comprising (a) barium titanate, (b) at least one of scandium oxide and yttrium oxide, (c) at least one of gadolinium oxide, terbium oxide[,] and dysprosium oxide, (d) manganese oxide, (e) cobalt oxide [,] and (f) nickel oxide, (2) magnesium oxide, and (3) SiO_2 - TiO_2 -MO-based oxide glass (wherein MO is as defined above) are compounded together with a binder and a solvent into a slurry and molded to prepare a dielectric ceramic layer 2 (green sheet). An internal electrode 4 [is formed] of nickel or a nickel alloy is formed on one side of the dielectric ceramic layer 2 by screen printing, vacuum evaporation or plating to obtain a dielectric ceramic layer 2b having an internal electrode 4 as shown in Fig. 2.

A requisite number of the dielectric ceramic layers 2b are piled up and press-bonded in between a pair of dielectric ceramic layers 2a having no internal electrode to obtain a laminate as shown in Fig. 3. The laminate of the dielectric ceramic layers 2a, 2b.[..

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14 OCT 1987

- 11 -

2b]..2b, 2a is calcined in a reducing atmosphere at a prescribed temperature to form a ceramic laminate 3.

An external electrode 5 is then formed on each side of the ceramic laminate 3 to make an electrical connection to the internal electrodes 4. The external electrodes 5 can be made of the same material as used for the internal electrodes 4. In addition, silver, palladium, [a] silver-palladium alloy, copper, [a] copper alloy, etc. are also useful. These metal powders may be used in combination with glass frits, such as B_2O_3 - SiO_2 -BaO-based glass frits or Li_2O - SiO_2 -BaO-based glass frits. The material of the external electrode should be selected appropriately taking into consideration the use of the resulting monolithic ceramic capacitor, the place of use, and the like. The external electrodes 5 can be formed by applying a paste of the metal powder selected to the ceramic laminate 3 (i.e., a calcined laminate) followed by baking. Alternatively, the paste may be applied to the laminate of the green sheets before calcination and baked to form the electrodes 5 and the ceramic laminate 3 simultaneously.

The external electrodes 5 are then plated with nickel, copper, etc. to form a first layer 6. Finally, the first layer 6 is plated with solder, tin, etc. to form a second layer 7, thereby to produce a monolithic ceramic capacitor 1 of the chip type.

As described above, the ceramic material used in the present invention does not undergo reduction and therefore does not change into a semiconductor even if calcined in a reducing atmosphere, which allows use of a base metal (nickel or a nickel alloy) as an electrode material. Further, calcination of the ceramic material can be achieved at a relatively low temperature of not

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14 OCT 1987

higher than 1300°C. As a result, both the material cost and the process cost of monolithic ceramic capacitors can be reduced.

The monolithic ceramic capacitor according to the present invention exhibits excellent characteristics, having a dielectric constant of not smaller than 3000, showing reduced variation in dielectric constant with temperature change, having a high insulation resistance, and undergoing no deterioration in characteristics under a high temperature or high humidity condition.

The grain size of the dielectric ceramic material according to the present invention is as small as about 1 μm or less. Therefore, if the thickness of dielectric ceramic layers constituting a monolithic ceramic capacitor is reduced, each layer can have a greater number of crystal grains than in conventional, monolithic ceramic capacitors. There is thus provided a highly reliable, small-sized, and yet high-capacity monolithic ceramic capacitor.

The present invention will now be illustrated in greater detail with reference to Examples, but it should be understood that the present invention is not construed as being limited thereto.

EXAMPLE 1

TiCl_4 and $\text{Ba}(\text{NO}_3)_2$, both having [a] varied purity were weighed and treated with oxalic acid to precipitate barium titanyl oxalate ($\text{BaTiO}(\text{C}_2\text{O}_4) \cdot 4\text{H}_2\text{O}$). The precipitate was thermally decomposed at or above 1000°C to synthesize 4 species of barium titanate (BaTiO_3) shown in Table 1 below.

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14 OCT 1987

- 13 -

Table 1						
Kind of BaTiO ₃	Content of Impurities (wt%)					Average Particle Size (μ m)
	Alkali Metal Oxide	SrO	CaO	SiO ₂	Al ₂ O ₃	
A	0.003	0.012	0.001	0.010	0.005	0.60
B	0.020	0.010	0.003	0.019	0.008	0.56
C	0.012	0.179	0.018	0.155	0.071	0.72
D	0.062	0.014	0.001	0.019	0.004	0.58

Oxides, carbonates or hydroxides of silicon, titanium, barium, strontium[,] and manganese were [weighted] weighed and mixed so as to give an SiO₂:TiO₂:BaO:SrO:MnO molar ratio of 0.60:0.25:0.10:0.02:0.03. The mixture was ground and evaporated to dryness to obtain powder. The powder was melted by heating in an aluminum crucible at 1300°C, quenched, and ground to obtain powdered oxide glass having an average particle size of not greater than 1 μ m.

[A composition] The compositions shown in Table 2 below [was] were compounded from (i) the barium titanate of Table 1, (ii) the powdered oxide glass prepared above, (iii) BaCO₃ serving for adjustment of the Ba/Ti molar ratio of barium titanate[,] and (iv) Sc₂O₃, Y₂O₃, Gd₂O₃, Tb₂O₃, Dy₂O₃, MnCO₃, NiO, Co₂O₃[,] and MgO₂ each having a purity of not lower than 99%.

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14 OCT 1997

Table 2

Sample No.		[(1- α - β)(BaO) ₂ •TiO ₂ + α {(1-x)M ₂ O ₃ + xRe ₂ O ₃ } + β (Mn _{1-y} Ni _y Co ₂ O)]																	MgO (mol %**)	Amount of Oxide Glass (part by weight***)
		Kind of BaTiO ₃	α	M		1-x	Re			x	β	β/α	y	z	y+z	m				
				Sc	Y		Gd	Tb	Dy											
1*	A	0.0000								0.00300			0.10	0.30	0.40	1.015	1.00	0.80		
2*	A	0.0120		0.80	0.80	0.20				0.0000						1.010	1.20	1.00		
3*	A	0.0100		1.00	1.00					0.00	0.0200	2.0	0.10	0.10	0.20	1.005	0.80	1.00		
4*	A	0.0150		0.80	0.80					0.20	0.0300	2.0	0.20	0.20	0.40	0.990	1.00	1.00		
5*	A	0.0150		0.70	0.70					0.30	0.0450	3.0	0.20	0.30	0.50	1.000	0.80	1.00		
6*	A	0.0200		0.80	0.80					0.20	0.0200	1.0	0.30	0.10	0.40	1.015	0.20	0.80		
7*	A	0.0150	0.10	0.70	0.80					0.20	0.0300	2.0	0.10	0.10	0.20	1.005	1.20	0.00		
8	A	0.0025		0.80	0.80	0.10				0.20	0.0025	1.0	0.10	0.10	0.20	1.010	1.00	0.20		
9	A	0.0250		0.70	0.70					0.30	0.0500	2.0	0.10	0.30	0.40	1.005	0.80	1.20		
10	A	0.0050	0.10	0.70	0.80			0.20		0.20	0.0240	4.0	0.10	0.30	0.40	1.010	1.20	1.00		
11	B	0.0100	0.50		0.50					0.50	0.0150	1.5	0.20	0.30	0.50	1.020	1.50	1.20		
12	C	0.0100		0.90	0.90					0.10	0.0050	0.5	0.00	0.50	0.50	1.010	1.00	1.00		
13	A	0.0150		0.80	0.80	0.20				0.20	0.0300	2.0	0.10	0.00	0.10	1.005	0.50	1.00		

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14 OCT 1987

14	A	0.0050				0.70	0.70			0.10	0.20	0.30	0.0150	3.0	0.00	0.00	0.00	1.005	5.00	1.20
15	A	0.0100				0.80	0.80	0.10	0.10	0.10	0.20		0.0300	3.0	0.10	0.30	0.40	1.035	0.80	1.20
16	A	0.0100				0.80	0.80	0.10	0.05	0.05	0.20	0.05	0.0200	2.0	0.10	0.10	0.20	1.010	1.00	3.00

Table 2 - Cont'd.																				
Sample No.	Kind of BaTiO ₃	α	M			1-x	Re			x	β	β/α	y	z	y+z	m	MgO (mol %**)	Amount of Oxide Glass (part by weight***)		
			α	M			Gd	Tb	Dy											
				Sc	Y															
17*	A	0.0300			0.80	0.80	0.20			0.20	0.0450	1.5	0.10	0.10	0.20	1.010	1.00	1.50		
18*	A	0.0200			0.80	0.80			0.20	0.20	0.0700	3.5	0.20	0.40	0.60	1.010	0.80	1.00		
19*	A	0.0050			0.70	0.70	0.10		0.20	0.30	0.0300	6.0	0.10	0.10	0.20	1.015	1.00	0.80		
20*	A	0.0150			0.20	0.20	0.80			0.80	0.0150	1.0	0.10	0.30	0.40	1.010	1.00	1.20		
21*	A	0.0150			0.80	0.80		0.20		0.20	0.0300	2.0	0.00	1.00	1.00	1.010	1.00	1.00		
22*	A	0.0050	0.10	0.70	0.80	0.80	0.20			0.20	0.0150	3.0	1.00	0.00	1.00	1.010	0.80	100		
23*	A	0.0100			0.70	0.70		0.30	0.30	0.30	0.0150	1.5	0.40	0.60	1.00	1.010	1.20	1.20		
24*	A	0.0100	0.20	0.60	0.80	0.80			0.20	0.20	0.0300	3.0	0.20	0.20	0.40	1.050	0.80	1.20		
25*	A	0.0100			0.70	0.70	0.30			0.30	0.0250	2.5	0.10	0.10	0.20	1.005	7.00	1.00		
26*	A	0.0050			0.70	0.70		0.30		0.30	0.0150	3.0	0.30	0.10	0.40	1.010	0.80	5.00		

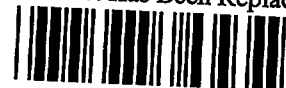
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14 OCT 1987

27*	D	0.0150	0.90	0.90	0.10			0.10	0.0300	2.0	0.20	0.20	0.40	1.010	1.20	1.00
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* Samples with an asterisk are those out of the scope of the invention.
** Based on the main component
*** Per 100 parts by weight of (main component + MgO)

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14 OCT 1997

- 17 -

The resulting mixture was kneaded in a ball mill in a wet process together with a polyvinyl butyral-based binder and an organic solvent, such as ethanol, to prepare a ceramic slurry. The slurry was shaped into a 11 μm thick rectangular green sheet by means of a doctor blade. A conductive paste mainly comprising nickel was screen printed on the ceramic green sheet to form a conductive paste layer one end of which reached the end of the green sheet.

A plurality of the ceramic green sheets were piled up in such a manner that the every other ceramic green sheet had its end with the internal electrode exposed arranged on one side of the resulting laminate. The laminate was heated at 350°C in a nitrogen atmosphere to burn the binder and then calcined at a temperature shown in Table 3 for 2 hours in a reducing atmosphere of $\text{H}_2\text{-N}_2\text{-H}_2\text{O}$ gas having an oxygen partial pressure of 10^9 to 10^{12} MPa to obtain a ceramic laminate.

The surface of the resulting ceramic laminate was observed under a scanning electron microscope [of] at 1500 magnifications to measure the grain size.

A silver paste containing $\text{B}_2\text{O}_3\text{-Li}_2\text{O-SiO}_2\text{-BaO-}$ based glass [frits] frit was applied onto both sides of the ceramic laminate where the internal electrodes were exposed and baked at 600°C in a nitrogen atmosphere to form an external electrode electrically connected to the internal electrodes.

The thus prepared monolithic ceramic capacitor had a width of 1.6 mm, a length of 3.2 mm[,] and a thickness of 1.2 mm. Each dielectric ceramic layer between two internal electrode layers had a thickness of 8 μm . The number of effective dielectric ceramic layers

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REPLACED

14 OCT 1997

- 18 -

was 19. The area of the opposing electrodes was 2.1 mm^2 per side.

The electric characteristics of the condenser were measured. The capacitance (C) and the dielectric loss ($\tan \delta$) were measured with an automatic bridge type meter at 1 kHz, 1 Vrms[,] and 25°C . From the capacitance was calculated the dielectric constant (ϵ). The insulation resistance (R) was measured by applying a direct voltage of 16 V for 2 minutes at 25°C and 125°C with an insulation resistance tester, and [a] the product of the capacitance (C) and the insulation resistance (R), i.e., CR product, was obtained.

Further, capacitance was measured at [a] varying [temperature] temperatures to determine [a] the percentage [of a] difference between capacitances measured at -25°C or 85°C and 20°C to the capacitance at 20°C (percentage change: $\Delta C/C_{20^\circ\text{C}}$), a percentage of a difference between capacitances measured at -55°C or 125°C and 25°C to the capacitance at 25°C (percentage change: $[C/C_{25^\circ\text{C}}] \Delta C/C_{25^\circ\text{C}}$), and the maximum absolute percentage change in capacitance measured in a temperature range of from -55 to 125°C ($|C|_{\text{max}}$).

The duration of the condenser was evaluated by a high-temperature loading test. A direct voltage of 100 V was applied to each of 36 condensers per sample at 150°C , and the insulation resistance (R) was measured with time. The time when the insulation resistance fell to $10^6 \Omega$ or lower was taken as [a] the life duration [of life], and an average duration of life was obtained for each sample.

Furthermore, the condenser was subjected to a high-humidity loading test[,] in which a direct voltage of 16 V was applied to each of 72 condensers per sample

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14 OCT 1987

at 121°C, 2 atm[,] and 100% RH, and the insulation resistance (R) was measured with time. The number of rejects whose insulation resistance (R) fell to $10^6 \Omega$ or lower before 250 hours from the start of the test was counted.

The results of the above measurements are shown in Table 3 below.

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14 OCT 1997

Table 3

Table 3														
Sample No.	Calcining Temp. (°C)	Dielectric Constant (ϵ)	Dielectric Loss [(tan δ)(%)]	Percentage Change in Capacitance $\Delta C/C_{25^\circ\text{C}}$ (%)			CR Product (25°C) (M Ω - μ F)	CR Product (125°C) (M Ω - μ F)	Average Duration of Life (hr)	Reject Rate in High-Humidity Loading Test	Grain Size (μ m)			
				-25°	85°	125°C								
1*	1300	2780	3.0	-4.9	17.4	-10.9	12.8	23.2	max	16V	2010	4	0/72	0.79
2*	1300	unmeasurable due to transformation into a semiconductor										2.7		
3*	1300	3380	2.1	0.0	-7.8	-0.6	-9.2	9.2	6350	1620	1620	311	0/72	0.74
4*	1280	unmeasurable due to transformation into a semiconductor										2.1		
5*	1280	3330	2.3	-0.3	-9.7	-0.7	-11.0	11.0	4120	710	710	102	0/72	0.73
6*	1280	3380	2.1	0.7	-13.6	0.9	-17.0	17.0	5310	1310	1310	303	0/72	0.74
7*	1360	unmeasurable due to undercalcination										0.61		
8	12801	3360	2.2	0.0	-10.0	-0.2	-11.4	11.4	7170	4820	4820	325	0/72	0.74
9	1300	3110	1.6	-0.1	-7.9	-0.2	-8.7	8.7	6140	2420	2420	437	0/72	0.68
10	1300	3300	1.8	0.2	-7.7	-0.6	-10.9	1309	7600	3150	3150	426	0/72	0.73
11	1300	3010	1.4	-0.1	-7.0	-0.8	-8.2	8.2	6680	2660	2660	389	0/72	0.60
12	1300	3260	1.7	0.1	-8.3	-0.2	-9.0	9.0	6140	2440	2440	482	0/72	0.76
13	1280	3080	1.5	-0.1	-7.1	-0.5	-8.8	8.8	7850	3080	3080	321	0/72	0.68
14	1300	3170	1.7	-0.3	-6.0	-1.3	-7.4	7.4	6340	2450	2450	419	0/72	0.69

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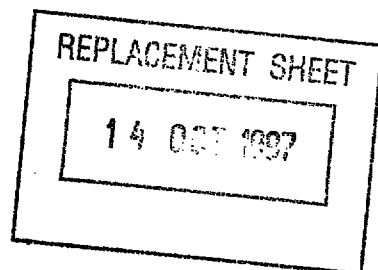
14 OCT 1987

Table 3 - Cont'd.

Sample No.	Calcining Temp. (°C)	Dielectric Constant (ε)	Dielectric Loss [(tan δ)(%)]	Percentage Change in Capacitance ΔC/C20°C (%)		Percentage Change in Capacitance ΔC/C25°C (%)		CR Product (25°C) (MΩ·μF)	CR Product (125°C) (MΩ·μF)	Average Duration of Life (hr)	Reject Rate in High-Humidity Loading Test	Grain Size (μm)
				-25°	85°	55°C	125°C					
15	1300	3300	2.0	0.1	-8.7	0.5	-9.9	6900	16V	379	0/72	0.72
16	1280	3080	1.3	0.8	-7.3	0.1	-12.1	6980	2810	370	0/72	0.71
17*	1360	2260	2.0	0.2	-7.7	-0.5	-9.0	4990	1560	284	12/72	0.64
18*	1300	3010	2.0	0.1	-9.8	-0.6	-16.0	5880	890	52	0/72	0.69
19*	1300	3560	2.3	1.2	-13.0	0.9	-19.5	6150	1430	298	0/72	0.76
20*	1300	3340	2.2	1.6	-15.9	0.9	-18.0	6700	2030	373	0/72	0.72
21*	1300	3200	1.7	0.1	-9.3	-0.1	-11.3	4580	720	173	0/72	0.71
22*	1300	3100	1.5	-0.3	-7.5	-1.2	-8.5	4650	860	192	0/72	0.69
23*	1280	3180	1.8	0.9	-9.7	-0.1	-12.1	4050	690	183	0/72	0.70
24*	1360											0.6
25*	1360	2570	1.1	-0.1	-6.0	-1.0	-7.2	5070	1600	353	48/72	0.66
26*	1260	2310	1.8	0.9	-13.1	0.6	-19.3	5120	2330	401	0/72	0.64
27*	1280	2370	1.6	0.4	-5.3	0.7	-6.1	6810	2490	498	0/72	0.64

unmeasurable due to undercalcination

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- 22 -

Samples with an asterisk are those out of the scope of the invention.

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THIS SHEET HAS BEEN
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14 OCT 1987

- 23 -

As is apparent from Tables 1 through 3, the monolithic ceramic capacitors according to the present invention have a dielectric constant (ϵ) of not smaller than 3000 and a dielectric loss ($\tan \delta$) of not more than 2.5%, and their percentage change in capacitance with temperature satisfies the B characteristics standard (JIS) between -25°C and 85°C and the X7R characteristics standard (EIA) between -55°C and 125°C. The insulation resistance at 25°C or 125°C, as expressed in terms of CR product, is as high as 6000 M Ω · μ F or more or 2000 M Ω · μ F or more, respectively. The average duration of life is as long as 300 hours or longer. The ceramic material used in these condensers can be calcined at relatively low temperatures of 1300°C or lower. The grain size of the ceramic is not greater than 1 μ m.

In the composition represented by formula $(1-\alpha-\beta)\{BaO\}_m \cdot TiO_2 + \alpha\{(1-x)M_2O_3 + xRe_2O_3\} + \beta(Mn_{1-y}Ni_yCo_z)O$ (wherein M_2O_3 and Re_2O_3 are as defined above), α should range from about 0.0025 to 0.025 [If α representing] and preferably about 0.006-0.015. If α , the amount of $(M_2O_3+Re_2O_3)_L$ is less than about 0.0025 as in sample 1, the dielectric constant ϵ is lower than 3000, the dielectric loss ($\tan \delta$) exceeds 2.5%, the capacity considerably varies with temperature change, and the average duration of life is extremely short.

If α exceeds about 0.025 as in sample 17, the dielectric constant does not exceed 3000, the insulation resistance at 25°C and 125°C is reduced, the average duration of life is short, a high calcining temperature is required, and rejects occur in a high-humidity loading test.

In the above formula, β representing the amount of (Mn, Ni, Co) should range from about 0.0025 to 0.05

This Sheet Has Been Replaced

THIS SHEET HAS BEEN
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REPLACEMENT SHEET

14 OCT 1987

and preferably about 0.005-0.03. If β is less than about 0.0025, the dielectric ceramic is reduced upon calcination in a reducing atmosphere and changes into a semiconductor having a reduced insulation resistance as is observed with sample 2.

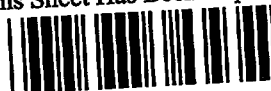
If β exceeds about 0.05, the insulation resistance is low, the average duration of life is short, and the variation in capacity with temperature change is large as is observed with sample 18.

The ratio β/α representing the ratio of the amount of (Mn, Ni, Co) to the amount of ($M_2O_3 + Re_2O_3$) should be about 4 or less and preferably about 3 or less. If it exceeds about 4, the variation in capacity with temperature change is large, the insulation resistance at 125°C is lower than 2000 $M\Omega \cdot \mu F$ (in terms of CR product), and the average duration of life is shorter than 300 hours as with sample 19.

x should be more than 0 and not more than about 0.50 and preferably about 0.1-0.3. If x is 0 as in sample 3, the insulation resistance is less than 2000 $M\Omega \cdot \mu F$ (CR product). If x exceeds about 0.5 as in sample 20, the variation in capacity with temperature change is too large to satisfy the B characteristics specified in JIS and the X7R characteristics specified by EIA standards.

m representing the molar ratio of barium titanate should be more than about 1.000 and not more than about 1.035 and preferably about 1.005-1.02. If it is less than about 1.000 the dielectric ceramic material is transformed into a semiconductor as is observed with sample 4. If it is 1.000 as in sample 5, the insulation resistance is low, and the average duration of life is shorter than 300 hours. If the molar ratio m exceeds

This Sheet Has Been Replaced



THIS SHEET HAS BEEN
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14 OCT 1987

- 25 -

about 1.035, the calcination properties are extremely poor as is observed with sample 24.

$y+z$ in the above formula should be 0 [or more and] to less than about 1.0, preferably about 0.1-0.5. If $y+z$ is 1.00 (i.e., Mn is absent) as in samples 21, 22 and 23, the insulation resistance is reduced, and the average duration of life is shorter than 300 hours.

The amount of magnesium oxide as a secondary component should range from about 0.5 to 5.0 mol in terms of MgO per 100 mol of the main component and preferably about 0.8-1.5. If it is less than about 0.5 mol as in sample 6, the insulation resistance is reduced, and the variation in capacity with temperature change becomes high. On the other hand, if the amount of MgO exceeds about 5 mol, the calcining temperature must be increased, and the reject rate in a high-humidity loading test is extremely high as with the case of sample 25.

The amount of the $\text{SiO}_2\text{-TiO}_2\text{-MO}$ -based oxide glass should be in a range of from about 0.2 to 3.0 parts by weight per 100 parts by weight of the total weight of the main component and the secondary component, MgO, and preferably about 1-1.5. If it is less than about 0.2 part as in sample 7, the ceramic material suffers from undercalcination. If it exceeds about 3.0 parts as in sample 26, the dielectric constant is low, the insulation resistance at 25°C does not exceed 6000 $\text{M}\Omega\cdot\mu\text{F}$ (CR product), and the variation in capacity with temperature change becomes larger.

The content of alkali metal oxide impurities in barium titanate should be about 0.02% by weight or less and preferably about 0.012. If it exceeds about 0.02% as in sample 27, reduction in dielectric constant results.

This Sheet Has Been ReplacedTHIS SHEET HAS BEEN
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14 OCT 1997

EXAMPLE 2

SiO_2 - TiO_2 -MO-based oxide [glass] glasses having an average particle size of not greater than $1\ \mu\text{m}$ and [a] the composition shown in Table 4 below were prepared by heating a raw material mixture at 1200 to 1500°C in the same manner as in Example 1. A hundred moles of a main component represented by compositional formula:
 $97.5\{\text{BaO}\}_{1.010}\cdot\text{TiO}_2 + 0.8\text{Y}_2\text{O}_3 + 0.2\text{Gd}_2\text{O}_3 + 1.5(\text{Mn}_{0.4}\text{Ni}_{0.2}\text{Co}_{0.4})\text{O}$
(molar ratio) in which barium titanate A shown in Table 1 was used, 1.0 mol of MgO, and 1.0% by weight, based on the total weight of the main component and MgO, of the above oxide glass were compounded to prepare a ceramic material.

** 1 A monolithic ceramic capacitor was produced in the same manner as in Example 1, except for using the above prepared ceramic material. The electrical characteristics of the resulting condenser were evaluated in the same manner as in Example 1. The results obtained are shown in Table 5 below.

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14 OCT 1997

Table 4

Sample No.	Amount of Oxide Glass Added (wt %)	Components of Oxide Glass													Additive Component (%)	
		Main Components (mol %)														
		SiO ₂	TiO ₂	MO							Total					
				BaO	CaO	SrO	MgO	ZnO	MnO							
101	1.0	85	1	1	-	-	-	-	4	9	14	-	-			
102	1.0	35	51	-	10	-	-	-	-	4	14	-	-			
103	1.0	30	20	-	30	-	15	-	4	1	50	-	-			
104	1.0	39	1	20	20	2	-	-	13	5	60	-	-			
105	1.0	70	10	5	5	-	-	-	10	-	20	-	-			
106	1.0	45	10	-	-	-	-	-	15	30	45	-	-			
107	1.0	50	20	10	10	3	7	-	-	-	30	-	-			
108	1.0	50	30	-	16	-	-	-	-	4	20	-	-			
109	1.0	35	30	25	10	-	-	-	-	-	35	-	-			
110	1.0	40	40	10	-	-	-	-	5	5	20	-	-			
111	1.0	45	22	3	30	-	-	-	-	-	33	15	-			
112	1.0	45	22	3	30	-	-	-	-	-	33	10	5			
113*	1.0	65	25	5	5	-	-	-	-	-	10	-	-			
114*	1.0	25	40	15	-	10	-	-	5	5	35	-	-			
115*	1.0	30	10	30	25	-	-	-	5	-	60	-	-			

REPLACEMENT SHEET

14 OCT 1997

Table 4 - Cont'd.

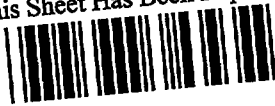
Table 4 - Cont'd.													
Sample No.	Amount of Oxide Glass Added (wt %)	Components of Oxide Glass											
		Main Components (mol %)										Additive Component (%)	
		SiO ₂	TiO ₂	MO									
				BaO	CaO	SiO	MgO	ZnO	MnO	Total			
116*	1.0	50	0	35	15	-	-	-	-	-	-	50	-
117*	1.0	45	22	30	-	-	3	-	-	-	-	33	25
118*	1.0	45	22	30	-	3	-	-	-	-	-	33	15
119*	1.0	30	66	10	-	-	-	-	-	-	-	10	-

Samples with an asterisk are those out of the scope of the invention.

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- 29 -

14 OCT 1997

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Table 5

Sample No.	Calcining Temp. (°C)	Dielectric Constant (ε)	Dielectric Loss [(tanδ)(%) K(tan δ)(%)	Percentage Change in Capacitance ΔC/C20°C (%)		Percentage Change in Capacitance ΔC/C25°C (%)			CR Product (25°C) (MΩ·μF)	CR Product (125°C) (MΩ·μF)	Average Duration of Life (hr)	Reject Rate in High-Humidity Loading Test	Grain Size (μm)
				-25°	-85°	55°C	125°C	max					
101	1300	3080	1.9	-1.2	-7.2	-2.3	-8.0	8.0	6520	2420	412	0/72	0.71
102	1300	3330	2.1	-1.0	-7.1	-1.6	-7.4	7.4	6120	2160	356	0/72	0.70
103	1300	3260	1.8	-0.9	-8.0	-0.4	-9.9	9.9	6830	2710	379	0/72	0.70
104	1300	3260	1.7	-1.4	-6.5	-1.7	-7.2	7.2	6580	2500	403	0/72	0.70
105	1280	3190	2.1	-0.9	-7.5	-1.5	-8.1	8.1	6470	2520	388	0/72	0.70
106	1280	3250	1.8	-1.3	-6.3	-1.6	-7.4	7.4	6510	2520	358	0/72	0.71
107	1300	3270	1.8	-1.2	-7.9	-1.6	-8.9	8.9	6330	2320	392	0/72	0.71
108	1280	3150	1.5	-0.5	-8.6	-0.1	-10.7	10.7	6760	2610	416	0/72	0.70
109	1280	3410	2.2	-1.1	-7.1	-1.6	-7.4	7.4	6540	2470	491	0/72	0.72
110	1280	3300	2.0	-0.3	-9.3	0.0	-11.3	11.3	6140	2190	338	0/72	0.71
111	1300	3110	1.9	-0.7	-7.8	-1.2	-8.8	8.8	7970	3460	590	0/72	0.70
112	1300	3070	1.8	-0.6	-8.4	-0.8	-12.7	12.7	7410	3380	585	0/72	0.71
113*	1360	2660	2.5	-2.1	-2.3	-2.8	1.5	3.0	4920	1710	36	53/72	0.66

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14 OCT 1997

114*		1360		unmeasurable due to undercalcination										0.61	
Table 5 - Cont'd.															
Sample No.	Calcining Temp. (°C)	Dielectric Constant (ε)	Dielectric Loss ((tanδ)(%) tan δ (%))	Percentage Change in Capacitance ΔC/C20°C (%)		Percentage Change in Capacitance ΔC/C25°C (%)		CR Product (25°C) (MΩ·μF)	CR Product (125°C) (MΩ·μF)	Average Duration of Life (hr)	Reject Rate in High-Humidity Loading Test	Grain Size (μm)			
				-25°	85°	55°C	125°C						max		
115*	1360							16V	16V						
unmeasurable due to undercalcination															
116*	1360	3290	2.2	-1.2	-7.5	-1.2	-2.6	9.6	6440	2280	72/72	0.70			
117*	1360														
unmeasurable due to undercalcination															
118*	1360											0.61			
unmeasurable due to undercalcination															
119*	1360											0.61			
unmeasurable due to undercalcination															

Samples with an asterisk are those out of the scope of the invention.

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14 OCT 1997

As is apparent from Tables 4 and 5, the monolithic ceramic capacitors constituted by the dielectric ceramic layers containing SiO_2 - TiO_2 -MO-based oxide glass according to the present invention exhibit a high dielectric constant (ϵ) of 3000 or more, a dielectric loss ($\tan \delta$) of not more than 2.5%, and their percentage change in capacitance with temperature satisfies the B characteristics standard (JIS) between -25°C and 85°C and the X7R characteristics standard (EIA) between -55°C and 125°C . The insulation resistance at 25°C or 125°C , as expressed in terms of CR product, is as high as $6000 \text{ M}\Omega \cdot \mu\text{F}$ or more or $2000 \text{ M}\Omega \cdot \mu\text{F}$ or more, respectively. The average duration of life is as long as 300 hours or longer. No rejects [was] were observed in the high-humidity loading test.

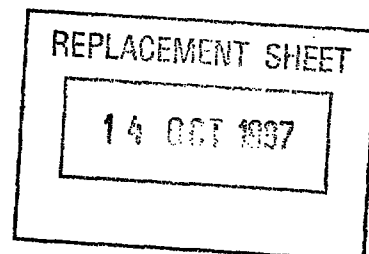
To the contrary, samples 113 to 116 and 119 showed undercalcination or developed rejects in the high-humidity loading test. That is, when the composition of SiO_2 - TiO_2 -MO-based oxide glass is plotted on a triangular diagram of (SiO_2 , TiO_2 , MO) (wherein MO is as defined above), the composition of the oxide glass used in these samples is not in the area surrounded by, or not on, four straight lines connecting four points: A (85,1,14), B (35,51,14), C (30,20,50), and D (39,1,60) (unit: mol%).

As is understood from the results of samples 111 and 112, addition of Al_2O_3 or ZrO_2 to the SiO_2 - TiO_2 -MO-based oxide glass is effective to provide a monolithic ceramic capacitor having an insulation resistance (CR product) of not lower than $7000 \text{ M}\Omega \cdot \mu\text{F}$ at 25°C and not lower than $3000 \text{ M}\Omega \cdot \mu\text{F}$ at 125°C . Note that addition of more than 15 parts by weight of Al_2O_3 or more than 5 parts by weight of ZrO_2 , per 100 parts by weight of the SiO_2 -

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TiO₂-MO-based oxide glass results in extreme reduction in sintering properties.

While the barium titanate powder used in the foregoing Examples is one prepared by an oxalic acid process, barium titanate powder prepared by an alkoxide process or a hydrothermal process can be used as well. In some cases, use of barium titanate powder prepared by an alkoxide process or a hydrothermal process can bring about better characteristics than demonstrated in the above Examples.

Further, while oxide powders, such as scandium oxide, yttrium oxide, gadolinium oxide, terbium oxide, dysprosium oxide, manganese oxide, cobalt oxide, nickel oxide[,] and magnesium oxide, were used as raw materials, the raw materials for the dielectric ceramic layers are not limited to these oxides. For example, a solution of an alkoxide or an organometallic compound of each metal element can be used as well as long as the resulting ceramic layer has the composition according to the present invention.

While the invention has been described in detail and with reference to specific embodiments thereof, it will be apparent to one skilled in the art that various changes and modifications can be made therein without departing from the spirit and scope thereof.

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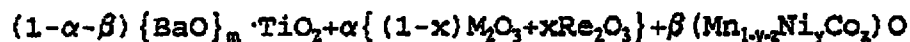
14 OCT 1987

- 33 -

WHAT IS CLAIMED IS:

1. A monolithic ceramic capacitor [having] comprising a laminate of a plurality of dielectric ceramic layers, [a plurality of] at least internal electrodes [each formed] between [every two] adjacent dielectric ceramic layers in such a manner that one end of each internal electrode is exposed at [one end] different ends of the dielectric ceramic layer alternately, and a pair of external electrodes each electrically connected to [the plurality of] different exposed internal electrodes [on each side of the laminate], in which said dielectric ceramic [layer comprises] layers comprise (a) barium titanate having an alkali metal oxide impurity content of not more than about 0.02% by weight, (b) at least one member selected from the group consisting of scandium oxide and yttrium oxide, (c) at least one member selected from the group consisting of gadolinium oxide, terbium oxide[,] and dysprosium oxide, (d) manganese oxide, (e) cobalt oxide[,] and (f) nickel oxide, and is [made up of] a material containing

(1) 100 mol of a main component represented by the compositional formula:



wherein M_2O_3 represents at least one member selected from the group consisting of Sc_2O_3 and Y_2O_3 ; Re_2O_3 represents at least one member selected from the group consisting of Gd_2O_3 , Tb_2O_3 [,] and Dy_2O_3 ; $0.0025 \leq \alpha \leq 0.025$; $0.0025 \leq \beta \leq 0.05$; $\beta/\alpha \leq 4$; $0 < x \leq 0.50$; $[0 \leq y \leq 1.0; 0 \leq z \leq 1.0]$ $0 \leq y \leq 1.0; 0 \leq z \leq 1.0$; $0 \leq y+z \leq 1.0$; and $1.000 < m \leq 1.035$,

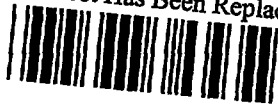
(2) about 0.5 to 5.0 mol, in terms of MgO, of magnesium oxide [as a secondary component,] and



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- 34 -

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14 OCT 1997

(3) about 0.2 to 3.0 parts by weight, per 100 parts by weight of the total weight of said main component (1) and said [secondary component] magnesium oxide (2), of SiO_2 - TiO_2 -MO-based oxide glass, wherein MO represents at least one member selected from the group consisting of BaO, CaO, SrO, MgO, ZnO[, and MnO[, and said internal electrodes are made up of nickel or a nickel alloy].

2. A monolithic ceramic capacitor according to claim 1, wherein the internal electrodes are of nickel or a nickel alloy.

3. A monolithic ceramic capacitor according to claim 2, wherein the alkali metal oxide impurity content of not more than about 0.012% by weight; M_2O_3 represents Y_2O_3 ; Re_2O_3 comprises Dy_2O_3 ; $0.006 \leq \alpha \leq 0.015$; $0.005 \leq \beta \leq 0.03$; $\beta/\alpha \leq 3$; $0.1 \leq x \leq 0.3$; $0.1 \leq v \leq 0.2$; $0.1 \leq z \leq 0.5$; $0.1 \leq y+z \leq 0.5$; and $1.005 \leq m \leq 1.02$; the amount of MgO is about 0.8-1.5 mol; the amount of glass is about 1-1.5 parts; and MO comprises CaO.

4. A monolithic ceramic capacitor according to claim 3, wherein the composition of said SiO_2 - TiO_2 -MO-based oxide glass is, when plotted on a triangular mol% diagram of (SiO_2 , TiO_2 , MO)[, wherein MO is at least one member selected from the group consisting of BaO, CaO, SrO, MgO, ZnO, and MnO,] in the area surrounded by, or on, four straight lines connecting four points: A (85,1,14), B (35,51,14), C (30,20,50), and D (39,1,60) [(unit: mol%)] and contains at least one of Al_2O_3 and ZrO_2 in a total amount of not more than 15 parts by weight per 100 parts by weight of the (SiO_2 , TiO_2 , MO) component,



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14 OCT 1997

provided that the amount of ZrO_2 is not more than 5 parts by weight.

[3] 5. A monolithic ceramic capacitor according to claim [1] 4, wherein said external electrodes [are each made up of] comprise a sintered layer of an electrically conductive metal powder or an electrically conductive metal powder containing glass [frits] frit.

[4] 6. A monolithic ceramic capacitor according to claim [1] 4, wherein said external electrodes [are each composed of] comprise a first layer made of a sintered layer of an electrically conductive metal powder or an electrically conductive metal layer containing glass [frits] frit and a second layer [that is formed] of plating on said first layer [by plating].

7. A monolithic ceramic capacitor according to claim 1, wherein the alkali metal oxide impurity content of not more than about 0.012% by weight; M_2O_3 represents Y_2O_3 ; Re_2O_3 comprises Dy_2O_3 ; $0.006 \leq \alpha \leq 0.015$; $0.005 \leq \beta \leq 0.03$; $\beta/\alpha \leq 3$; $0.1 \leq x \leq 0.3$; $0.1 \leq y \leq 0.2$; $0.1 \leq z \leq 0.5$; $0.1 \leq y+z \leq 0.5$; and $1.005 \leq m \leq 1.02$; the amount of MgO is about 0.8-1.5 mol; the amount of glass is about 1-1.5 parts; and MO comprises CaO .

8. A monolithic ceramic capacitor according to claim 7, wherein the composition of said SiO_2 - TiO_2 - MO -based oxide glass is, when plotted on a triangular mol% diagram of (SiO_2 , TiO_2 , MO) in the area surrounded by, or on, four straight lines connecting four points: A (85,1,14), B (35,51,14), C (30,20,50), and D (39,1,60)

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14 OCT 1987

and contains at least one of Al_2O_3 and ZrO_2 in a total amount of not more than 15 parts by weight per 100 parts by weight of the (SiO_2 , TiO_2 , MO) component, provided that the amount of ZrO_2 is not more than 5 parts by weight.

9. A monolithic ceramic capacitor according to claim 8, wherein said external electrodes comprise a sintered layer of an electrically conductive metal powder or an electrically conductive metal powder containing glass frit.

10. A monolithic ceramic capacitor according to claim 8, wherein said external electrodes comprise a first layer made of a sintered layer of an electrically conductive metal powder or an electrically conductive metal layer containing glass frit and a second layer of plating on said first layer.

11. A monolithic ceramic capacitor according to claim 1, wherein the composition of said SiO_2 - TiO_2 - MO -based oxide glass is, when plotted on a triangular mol% diagram of (SiO_2 , TiO_2 , MO) in the area surrounded by, or on, four straight lines connecting four points: A (85,1,14), B (35,51,14), C (30,20,50), and D (39,1,60) and contains at least one of Al_2O_3 and ZrO_2 in a total amount of not more than 15 parts by weight per 100 parts by weight of the (SiO_2 , TiO_2 , MO) component, provided that the amount of ZrO_2 is not more than 5 parts by weight.

12. A monolithic ceramic capacitor according to claim 11, wherein said external electrodes comprise a sintered layer of an electrically conductive metal powder



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or an electrically conductive metal powder containing glass frit.

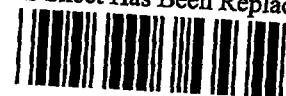
13. A monolithic ceramic capacitor according to claim 11, wherein said external electrodes comprise a first layer made of a sintered layer of an electrically conductive metal powder or an electrically conductive metal layer containing glass frit and a second layer of plating on said first layer.

14. A monolithic ceramic capacitor according to claim 1, wherein said external electrodes comprise a sintered layer of an electrically conductive metal powder or an electrically conductive metal powder containing glass frit.

15. A monolithic ceramic capacitor according to claim 1, wherein said external electrodes comprise a first layer made of a sintered layer of an electrically conductive metal powder or an electrically conductive metal layer containing glass frit and a second layer of plating on said first layer.



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14 OCT 1997

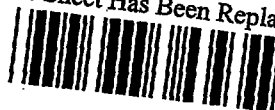
MONOLITHIC CERAMIC CAPACITOR

ABSTRACT OF THE DISCLOSURE

A monolithic ceramic capacitor having a plurality of dielectric ceramic layers, [a plurality of] internal electrodes, and [a pair of] external electrodes [each] electrically connected to the internal electrode, wherein the dielectric ceramic [layer comprises] layers comprise (a) barium titanate having an alkali metal oxide impurity content of not more than about 0.02% by weight, (b) [at least one member selected from the group consisting of] scandium oxide [and] and/or yttrium oxide, (c) [at least one member selected from the group consisting of] gadolinium oxide, terbium oxide[, and] and/or dysprosium oxide, (d) manganese oxide, (e) cobalt oxide, and (f) nickel oxide, and is [made up of] a material containing (1) 100 [mol of a main component] mols represented by the compositional formula:

$(1-\alpha-\beta)\{BaO\}_m \cdot TiO_2 + \alpha\{(1-x)M_2O_3 + xRe_2O_3\} + \beta(Mn_{1-y}Ni_zCo_z)_O$
wherein M_2O_3 represents [at least one member selected from the group consisting of Sc_2O_3 and Y_2O_3 ; Re_2O_3 represents at least one member selected from the group consisting of Gd_2O_3 , Tb_2O_3 , and Dy_2O_3 ; $0.0025 \leq \alpha \leq 0.025$] said (b); Re_2O_3 represents said (c); $0.0025 \leq \beta \leq 0.05$; $\beta/\alpha \leq 4$; $0 < x \leq 0.50$; $0 \leq y \leq 1.0$; $0 \leq z \leq 1.0$; $0 \leq y+z < 1.0$; and $1.000 < m \leq 1.035$, (2) about 0.5 to 5.0 mol, in terms of MgO, of magnesium oxide [as a secondary component,] and (3) about 0.2 to 3.0 parts by weight, per 100 [parts by weight of the total weight of said main component (1) and said secondary component] pph of components (1) and (2), of SiO_2 - TiO_2 -MO-based oxide glass (wherein MO represents at least one member selected from the group consisting of BaO, CaO, SrO, MgO, ZnO, and

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14 OCT 1997

MnO) [, and said] . ~~Said~~ internal electrodes [are made up of] can be nickel or a nickel alloy[, is disclosed] .

FIG. 4

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14 OCT 1997

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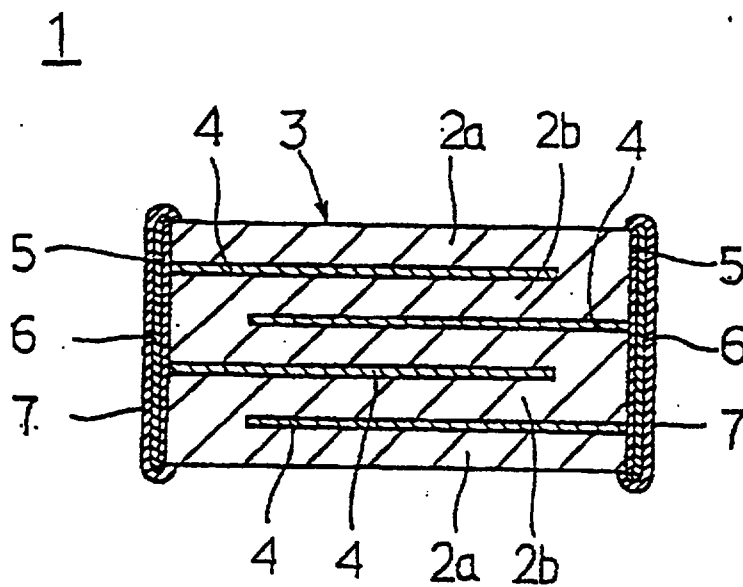


FIG. 1

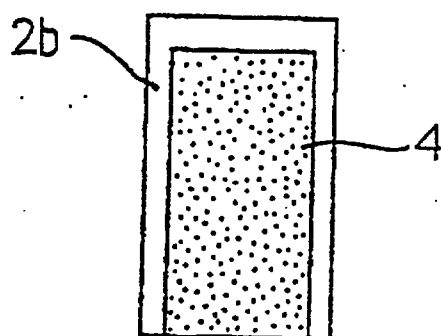


FIG. 2

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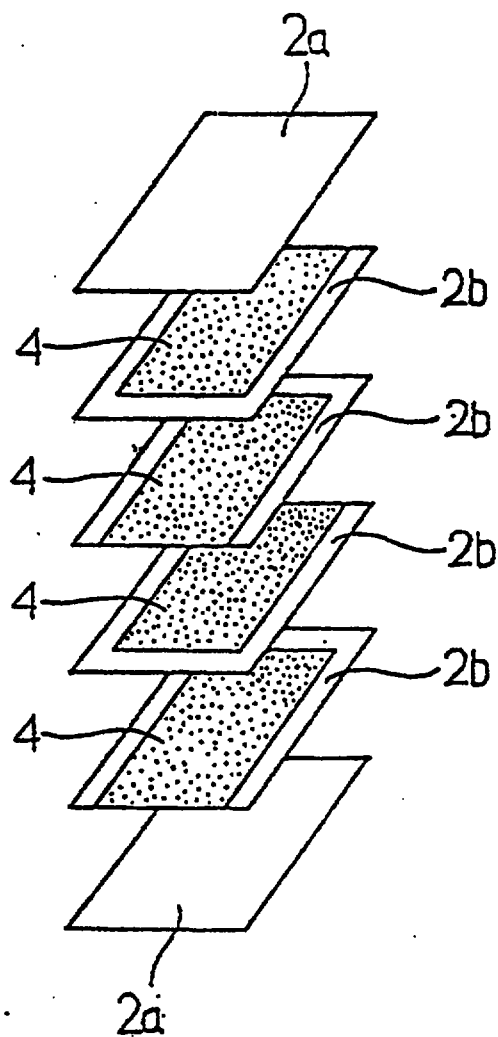
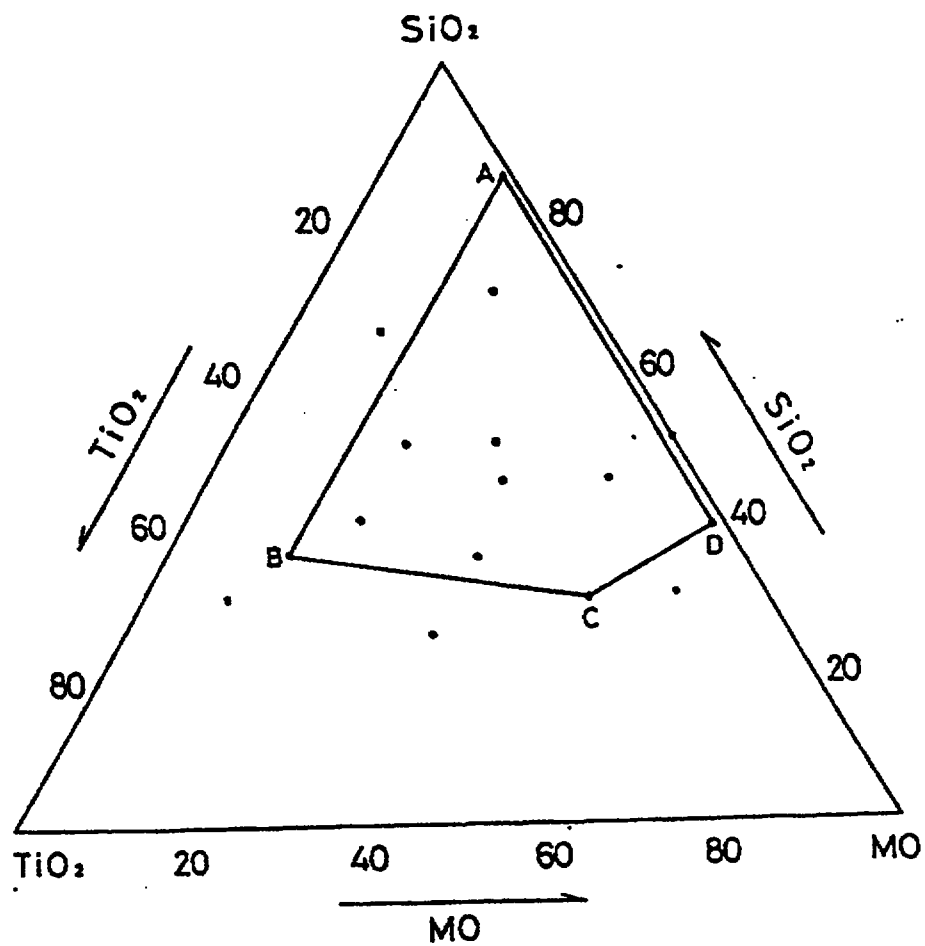


FIG. 3

14 OCT 1997

3FIG. 4

13 NOV 1987

- 1 -

MONOLITHIC CERAMIC CAPACITORFIELD OF THE INVENTION

This invention relates to a ceramic capacitor, more particularly a monolithic ceramic capacitor having internal electrodes made of nickel or a nickel alloy.

BACKGROUND OF THE INVENTION

A monolithic ceramic capacitor is generally produced according to the following procedures. Dielectric ceramic layers in sheet form having applied thereon an electrode material to serve as an internal electrode are prepared. A ceramic material mainly comprising, e.g., BaTiO_3 , is used as a dielectric ceramic layer. A plurality of the dielectric ceramic layers with the electrode material are piled up and press-bonded under heat into one body. The resulting laminate is calcined at 1250 to 1350°C to obtain a ceramic laminate having internal electrodes. An external electrode is baked onto both sides of the ceramic laminate to make an electrical connection to the internal electrodes and obtain a monolithic ceramic capacitor.

The material for the internal electrodes are required to satisfy the following conditions:

1. To have a melting point at or above the calcining temperature of the ceramic laminate because the internal electrodes and the ceramic laminate are calcined simultaneously.

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12 NOV 1987

2. To be resistant to oxidation in a high-temperature oxidative atmosphere and be unreactive with the dielectric ceramic layer.

Noble metals, such as platinum, gold, palladium and a silver-palladium alloy, have been used as an electrode material satisfying these requirements. While excellent in performance, these electrode materials are so expensive that the proportion of the electrode material cost reaches 30 to 70% of the entire material cost, which has been the greatest factor of increasing the production cost of monolithic ceramic capacitors.

In addition to noble metals, base metals, such as Ni, Fe, Co, W and Mo, also have a high melting point. However, these base metals are readily oxidized in a high-temperature oxidative atmosphere,

causing them to fail to perform their function as an electrode. Therefore, calcination of the base metal together with dielectric ceramic layers must be carried out in a neutral or reducing atmosphere before they can be used as an internal electrode of a monolithic ceramic capacitor. However, the problem is that a conventional dielectric ceramic material undergoes vigorous reduction into a semiconductor if calcined in a neutral or reducing atmosphere.

Dielectric ceramic materials which have been proposed in order to solve the above problem include a dielectric ceramic material comprising a barium titanate solid solution having a barium site to titanium site ratio in excess of a stoichiometric one (see JP-B-57-42588, the term "JP-B" as used herein means an "examined published Japanese patent application") and a dielectric ceramic material comprising a barium titanate solid

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13 NOV 1997

solution having incorporated therein an oxide of a rare earth metal, such as La, Nd, Sm, Dy or Y (see JP-A-61-101459, the term "JP-A" as used herein means an "unexamined published Japanese patent application").

On the other hand, dielectric ceramic materials whose dielectric constant has reduced temperature dependence, such as $\text{BaTiO}_3\text{-CaZrO}_3\text{-MnO-MgO}$ system (see JP-A-62-256422) and $\text{BaTiO}_3\text{-(Mg, Zn, Sr or Ca)O-B}_2\text{O}_3\text{-SiO}_2$ system (see JP-B-61-14611), have also been proposed.

Use of these dielectric ceramic materials have made it possible to obtain a ceramic laminate that is not transformed into a semiconductor even when calcined in a reducing atmosphere, thereby making it feasible to produce a monolithic ceramic capacitor in which a base metal, such as nickel, is used as an internal electrode.

In recent years, size reduction of electronic components has accelerated rapidly in the development of electronics. Monolithic ceramic capacitors have also showed a remarkable tendency to reduction in size and increase in capacity. There has thus been an increasing demand for a dielectric ceramic material which has a high dielectric constant, shows reduced variation in dielectric constant with temperature change, and is thereby highly reliable.

The dielectric ceramic materials disclosed in JP-B-57-42588 and JP-A-61-101459 exhibit a high dielectric constant but have a large crystal grain size on calcination. When they are applied to a monolithic ceramic capacitor in which each dielectric ceramic layer has a small thickness such as 10 μm or less, the number of crystal grains existing per layer is decreased, resulting in diminished reliability. Besides, these materials undergo considerable variation in dielectric

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13 NOV 1997

constant with temperature change and are ~~not regarded to~~ meet the demands of the market sufficiently.

The dielectric ceramic material disclosed in JP-A-62-256422, on the other hand, exhibits a relatively high dielectric constant and provides on calcination, a ceramic laminate having a small crystal grain size and small variation of dielectric constant with temperature change. However, CaZrO_3 and CaTiO_3 produced on calcination tend to form a secondary phase together with MnO , etc., which has made the resulting monolithic ceramic capacitor less reliable in high temperatures.

The dielectric ceramic material disclosed in JP-B-61-14611 exhibits a dielectric constant of 2000 to 2800, which is disadvantageous for achieving size reduction and capacity increase in a monolithic ceramic capacitor. Moreover, the material fails to fulfill the requirement of X7R characteristics specified by EIA (Electronic Industries Association) standards

that the percentage of change in electrostatic capacity be within a range of $\pm 15\%$ in the temperature range of from -55°C to $+125^\circ\text{C}$.

Although JP-A-5-9066, JP-A-5-9067, and JP-A-5-9068 have proposed ceramic compositions in order to eliminate these problems, the ever-continuing demand for size reduction and capacity increase has been producing a keen demand for dielectric ceramic materials with greater reliability. At the same time, demand for thickness reduction of a ceramic dielectric layer has been getting intenser.

Thus, there has been the necessity for the development of a small-sized and high-capacity monolithic ceramic capacitor having excellent reliability in a high temperature and high humidity environment.

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SUMMARY OF THE INVENTION

An object of the present invention is to provide an economical, small-sized and high-capacity monolithic ceramic capacitor which has a dielectric constant of 3000 or higher and an insulation resistance as high as 6000 MΩ·μF or more at room temperature or 2000 MΩ·μF or more at 125°C, as expressed in terms of the product of capacitance and insulation resistance (CR product), and whose capacity exhibits temperature characteristics satisfying the B characteristics specified by JIS (Japanese Industrial Standards) and the X7R characteristics specified by EIA standards, and which has excellent weathering performance in, for example, loading in high temperature or high humidity.

The present invention provides a monolithic ceramic capacitor having a laminate of a plurality of dielectric ceramic layers, a plurality of internal electrodes each formed between two adjacent dielectric ceramic layers in such a manner that one end of each internal electrode is exposed at one end of the dielectric ceramic layer alternately, and a pair of external electrodes each electrically connected to the plurality of exposed internal electrodes of the laminate, in which the dielectric ceramic layer comprises (a) barium titanate having an alkali metal oxide impurity content of not more than about 0.02% by weight, (b) at least one member selected from the group consisting of scandium oxide and yttrium oxide, (c) at least one member selected from the group consisting of gadolinium oxide terbium oxide and dysprosium oxide, (d) manganese oxide, (e) cobalt oxide and (f) nickel oxide, and is made up of a material containing (1)

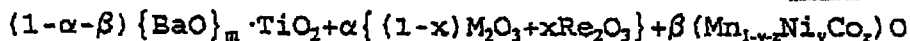
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13 NOV 1997

100 mol of a main component represented by the compositional formula:



wherein M_2O_3 represents at least one member selected from the group consisting of Sc_2O_3 and Y_2O_3 ; Re_2O_3 represents at least one member selected from the group consisting of Gd_2O_3 , Tb_2O_3 , and Dy_2O_3 ; $0.0025 \leq \alpha \leq 0.025$; $0.0025 \leq \beta \leq 0.05$; $\beta/\alpha \leq 4$; $0 < x \leq 0.50$; $0 \leq y \leq 1.0$; $0 \leq z \leq 1.0$; $0 \leq y+z < 1.0$; and $1.000 < m \leq 1.035$, (2) about 0.5 to 5.0 mol, in terms of MgO , of magnesium oxide as a secondary component, and (3) about 0.2 to 3.0 parts by weight, per 100 parts by weight of the total weight of the main component (1) and the secondary component (2), of SiO_2 - TiO_2 -MO-based oxide glass (wherein MO represents at least one member selected from the group consisting of BaO , CaO , SrO , MgO , ZnO , and MnO), and the internal electrodes are made up of nickel or a nickel alloy.

In a preferred embodiment of the monolithic ceramic capacitor of the present invention, the composition of the SiO_2 - TiO_2 -MO-based oxide glass is, when plotted on a triangular diagram of (SiO_2 , TiO_2 , MO) (wherein MO is as defined above), in the area surrounded by, or on, four straight lines connecting four points: A (85,1,14), B (35,51,14), C (30,20,50), and D (39,1,60) (unit: mol%), and contains at least one of Al_2O_3 and ZrO_2 in a total amount of not more than about 15 parts by weight per 100 parts by weight of the (SiO_2 , TiO_2 , MO) component, provided that the amount of ZrO_2 is not more than about 5 parts by weight.

In another preferred embodiment, the external electrode is made up of a sintered layer of an electrically conductive metal powder which may contain

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13 NOV 1997

glass frit. In a still preferred embodiment, the external electrode is composed of a first layer made of a sintered layer of an electrically conductive metal powder which may contain glass frit and a second layer that is formed on the first layer by plating.

BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 is a schematic cross section of a monolithic ceramic capacitor according to one embodiment of the present invention.

Fig. 2 is a schematic plan of a ceramic layer with an internal electrode which is used in the monolithic ceramic capacitor of Fig. 1.

Fig. 3 is a perspective exploded view of the ceramic laminate used in the monolithic ceramic capacitor of Fig. 1.

Fig. 4 is a triangular diagram of (SiO_2 , TiO_2 , MO) showing a preferred range of the composition of SiO_2 - TiO_2 -MO-based oxide glass.

DETAILED DESCRIPTION OF THE INVENTION

In the monolithic ceramic capacitor of the present invention, the dielectric ceramic layers are obtained by calcining a dielectric ceramic material comprising (1) (a) barium titanate, (b) at least one of scandium oxide and yttrium oxide, (c) at least one of gadolinium oxide, terbium oxide and dysprosium oxide, (d) manganese oxide, (e) cobalt oxide and (f) nickel oxide at a ratio shown by the above-described compositional formula having incorporated therein (2) magnesium oxide and (3) SiO_2 - TiO_2 -MO-based oxide glass (wherein MO represents at least one member selected from the group consisting of BaO, CaO, SrO, MgO, ZnO, and

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13 NOV 1987

MnO). The dielectric ceramic material can be calcined in a reducing atmosphere without suffering from deterioration of characteristics to provide a highly reliable monolithic ceramic capacitor whose capacity exhibits temperature characteristics satisfying the B characteristics specified by JIS and the X7R characteristics specified by EIA standards, and which exhibits high insulation resistance at room temperature and high temperature.

In the resulting dielectric ceramic laminate, the crystal grains are as small as 1 μm or less so that the grains increase in number per layer. This will secure a sufficient reliability even though the thickness of the dielectric ceramic layer in the laminate is reduced.

The barium titanate constituting the main component (1) contains, as impurities, alkaline earth metal oxides (e.g., SrO and CaO), alkali metal oxides (e.g., Na₂O and K₂O), and other oxides (e.g., Al₂O₃ and SiO₂). Of these impurities, the alkali metal oxides, such as Na₂O and K₂O, have been confirmed to be greatly influential on the electrical characteristics. It was proved that a dielectric constant of not smaller than 3000 can be obtained by using barium titanate having an alkali metal oxide content of not more than about 0.02% by weight and preferably about 0.012% or less.

It has also been found that incorporation of oxide glass mainly comprising SiO₂-TiO₂-MO (wherein MO is at least one member selected from the group consisting of BaO, CaO, SrO, MgO, ZnO, and MnO) into the dielectric ceramic layers brings about improved sintering properties and improved resistance to plating. Further, addition of

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13 NOV 1987

Al_2O_3 and/or ZrO_2 to the oxide glass makes it possible to obtain higher insulation resistance.

Dielectric ceramic layers made from the above-described dielectric ceramic material provide a highly reliable, small-sized, and high-capacity monolithic ceramic capacitor, the capacity of which shows reduced variation with temperature. Use of the dielectric ceramic material makes it feasible to use nickel or a nickel alloy as an internal electrode. It is also possible to use nickel or a nickel alloy in combination with a small amount of ceramic powder.

The external electrode is not particularly limited in composition. For example, it can be a sintered layer of a conductive powder of various metals (e.g., Ag, Pd, Ag-Pd, Cu and Cu alloys) or a sintered layer of a mixture of such a conductive metal powder and glass frits of various kinds (e.g., B_2O_3 - Li_2O - SiO_2 -BaO-based glass frits, B_2O_3 - SiO_2 -BaO-based glass frits, Li_2O - SiO_2 -BaO-based glass frits, B_2O_3 - SiO_2 -ZnO-based glass frits). Ceramic powder may be used in a small proportion with the conductive metal powder (and glass frits). It is preferable that the sintered layer is plated with Ni, Cu, an Ni-Cu alloy, etc. The plated layer may further be plated with solder, tin, etc.

A monolithic ceramic capacitor according to one embodiment of the present invention will be described by referring to the accompanying drawings.

Fig. 1 is a schematic cross section of the monolithic ceramic capacitor. Fig. 2 is a schematic plan of a ceramic layer having an internal electrode used in the monolithic ceramic capacitor of this embodiment.

Fig. 3 is a perspective exploded view of the ceramic

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13 NOV 1997

laminate used in the monolithic ceramic capacitor of this embodiment.

As shown in Fig. 1, the monolithic ceramic capacitor 1 is of rectangular chip type having a ceramic laminate 3 composed of a plurality of dielectric ceramic layers 2a and 2b, with an internal electrode 4 being interposed between every two ceramic layers. On each side of the ceramic laminate 3 are formed an external electrode 5, a first plating layer 6 formed by plating with nickel, copper, etc., and a second plating layer 7 formed by plating with solder, tin, etc.

The monolithic ceramic capacitor 1 shown in Fig. 1 can be produced as follows.

(1) A main component comprising (a) barium titanate, (b) at least one of scandium oxide and yttrium oxide, (c) at least one of gadolinium oxide, terbium oxide and dysprosium oxide, (d) manganese oxide, (e) cobalt oxide and (f) nickel oxide, (2) magnesium oxide, and (3) $\text{SiO}_2\text{-TiO}_2\text{-MO}$ -based oxide glass (wherein MO is as defined above) are compounded together with a binder and a solvent into a slurry and molded to prepare a dielectric ceramic layer 2 (green sheet). An internal electrode 4 of nickel or a nickel alloy is formed on one side of the dielectric ceramic layer 2 by screen printing, vacuum evaporation or plating to obtain a dielectric ceramic layer 2b having an internal electrode 4 as shown in Fig. 2.

A requisite number of the dielectric ceramic layers 2b are piled up and press-bonded in between a pair of dielectric ceramic layers 2a having no internal electrode to obtain a laminate as shown in Fig. 3. The laminate of the dielectric ceramic layers 2a, 2b.

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13 NOV 1997

..2b, 2a is calcined in a reducing atmosphere at a prescribed temperature to form a ceramic laminate 3.

An external electrode 5 is then formed on each side of the ceramic laminate 3 to make an electrical connection to the internal electrodes 4. The external electrodes 5 can be made of the same material as used for the internal electrodes 4. In addition, silver, palladium, silver-palladium alloy, copper, copper alloy, etc. are also useful. These metal powders may be used in combination with glass frits, such as B_2O_3 - SiO_2 -BaO-based glass frits or Li_2O - SiO_2 -BaO-based glass frits. The material of the external electrode should be selected appropriately taking into consideration the use of the resulting monolithic ceramic capacitor, the place of use, and the like. The external electrodes 5 can be formed by applying a paste of the metal powder selected to the ceramic laminate 3 (i.e., a calcined laminate) followed by baking. Alternatively, the paste may be applied to the laminate of the green sheets before calcination and baked to form the electrodes 5 and the ceramic laminate 3 simultaneously.

The external electrodes 5 are then plated with nickel, copper, etc. to form a first layer 6. Finally, the first layer 6 is plated with solder, tin, etc. to form a second layer 7, thereby to produce a monolithic ceramic capacitor 1 of the chip type.

As described above, the ceramic material used in the present invention does not undergo reduction and therefore does not change into a semiconductor even if calcined in a reducing atmosphere, which allows use of a base metal (nickel or a nickel alloy) as an electrode material. Further, calcination of the ceramic material can be achieved at a relatively low temperature of not

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12 NOV 1997

higher than 1300°C. As a result, both the material cost and the process cost of monolithic ceramic capacitors can be reduced.

The monolithic ceramic capacitor according to the present invention exhibits excellent characteristics, having a dielectric constant of not smaller than 3000, showing reduced variation in dielectric constant with temperature change, having a high insulation resistance, and undergoing no deterioration in characteristics under a high temperature or high humidity condition.

The grain size of the dielectric ceramic material according to the present invention is as small as about 1 μm or less. Therefore, if the thickness of dielectric ceramic layers constituting a monolithic ceramic capacitor is reduced, each layer can have a greater number of crystal grains than in conventional monolithic ceramic capacitors. There is thus provided a highly reliable, small-sized, and yet high-capacity monolithic ceramic capacitor.

The present invention will now be illustrated in greater detail with reference to Examples, but it should be understood that the present invention is not construed as being limited thereto.

EXAMPLE 1

TiCl_4 and $\text{Ba}(\text{NO}_3)_2$, both having varied purity were weighed and treated with oxalic acid to precipitate barium titanyl oxalate ($\text{BaTiO}(\text{C}_2\text{O}_4) \cdot 4\text{H}_2\text{O}$). The precipitate was thermally decomposed at or above 1000°C to synthesize 4 species of barium titanate (BaTiO_3) shown in Table 1 below.

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13 NOV 1997

Table 1						
Kind of BaTiO ₃	Content of Impurities (wt%)					Average Particle Size (μm)
	Alkali Metal Oxide	SrO	CaO	SiO ₂	Al ₂ O ₃	
A	0.003	0.012	0.001	0.010	0.005	0.60
B	0.020	0.010	0.003	0.019	0.008	0.56
C	0.012	0.179	0.018	0.155	0.071	0.72
D	0.062	0.014	0.001	0.019	0.004	0.58

Oxides, carbonates or hydroxides of silicon, titanium, barium, strontium and manganese were weighed and mixed so as to give an SiO₂:TiO₂:BaO:SrO:MnO molar ratio of 0.60:0.25:0.10:0.02:0.03. The mixture was ground and evaporated to dryness to obtain powder. The powder was melted by heating in an aluminum crucible at 1300°C, quenched, and ground to obtain powdered oxide glass having an average particle size of not greater than 1 μm.

The compositions shown in Table 2 below were compounded from (i) the barium titanate of Table 1, (ii) the powdered oxide glass prepared above, (iii) BaCO₃ serving for adjustment of the Ba/Ti molar ratio of barium titanate and (iv) Sc₂O₃, Y₂O₃, Gd₂O₃, Tb₂O₃, Dy₂O₃, MnCO₃, NiO, Co₂O₃ and MgO, each having a purity of not lower than 99%.

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13 NOV 1997

Table 2

Sample No.	Kind of BaTiO ₃	α	M		1-x	Re			x	β	β/α	y	z	y+z	m	MgO (mol %**)	Amount of Oxide Glass (part by weight***)
			Sc	Y		Gd	Tb	Dy									
1*	A	0.0000								0.00300		0.10	0.30	0.40	1.015	1.00	0.80
2*	A	0.0120		0.80	0.80	0.20			0.20	0.0000					1.010	1.20	1.00
3*	A	0.0100		1.00	1.00				0.00	0.0200	2.0	0.10	0.10	0.20	1.005	0.80	1.00
4*	A	0.0150		0.80	0.80				0.20	0.0300	2.0	0.20	0.20	0.40	0.990	1.00	1.00
5*	A	0.0150		0.70	0.70				0.30	0.0450	3.0	0.20	0.30	0.50	1.000	0.80	1.00
6*	A	0.0200		0.80	0.80				0.20	0.0200	1.0	0.30	0.10	0.40	1.015	0.20	0.80
7*	A	0.0150	0.10	0.70	0.80				0.20	0.0300	2.0	0.10	0.10	0.20	1.005	1.20	0.00
8	A	0.0025		0.80	0.80	0.10			0.20	0.0025	1.0	0.10	0.10	0.20	1.010	1.00	0.20
9	A	0.0250		0.70	0.70				0.30	0.0500	2.0	0.10	0.30	0.40	1.005	0.80	1.20
10	A	0.0060	0.10	0.70	0.80		0.20		0.20	0.0240	4.0	0.10	0.30	0.40	1.010	1.20	1.00
11	B	0.0100	0.50		0.50				0.50	0.0150	1.5	0.20	0.30	0.50	1.020	1.50	1.20
12	C	0.0100		0.90	0.90				0.10	0.0050	0.5	0.00	0.50	0.50	1.010	1.00	1.00
13	A	0.0150		0.80	0.80	0.20			0.20	0.0300	2.0	0.10	0.00	0.10	1.005	0.50	1.00

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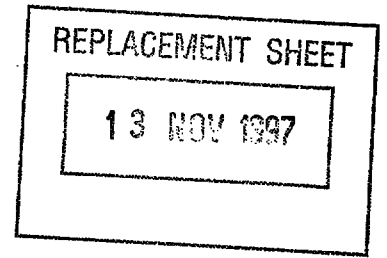
14	A	0.0050		0.70	0.70		0.10	0.20	0.30	0.0150	3.0	0.00	0.00	0.00	1.005	5.00	1.20
15	A	0.0100		0.80	0.80	0.10	0.10		0.20	0.0300	3.0	0.10	0.30	0.40	1.035	0.80	1.20
16	A	0.0100		0.80	0.80	0.10	0.05	0.05	0.20	0.0200	2.0	0.10	0.10	0.20	1.010	1.00	3.00

Table 2 - Cont'd.																	
Sample No.	Kind of BaTiO ₃	α	M		1-x	Re			x	β	β/α	y	z	y+z	m	MgO (mol %**)	Amount of Oxide Glass (part by weight(***))
			Sc	Y		Gd	Tb	Dy									
17*	A	0.0300		0.80	0.80	0.20			0.20	0.0450	1.5	0.10	0.10	0.20	1.010	1.00	1.50
18*	A	0.0200		0.80	0.80			0.20	0.20	0.0700	3.5	0.20	0.40	0.60	1.010	0.80	1.00
19*	A	0.0050		0.70	0.70	0.10		0.20	0.30	0.0300	6.0	0.10	0.10	0.20	1.015	1.00	0.80
20*	A	0.0150		0.20	0.20	0.80			0.80	0.0150	1.0	0.10	0.30	0.40	1.010	1.00	1.20
21*	A	0.0150		0.80	0.80		0.20		0.20	0.0300	2.0	0.00	1.00	1.00	1.010	1.00	1.00
22*	A	0.0050	0.10	0.70	0.80	0.20			0.20	0.0150	3.0	1.00	0.00	1.00	1.010	0.80	1.00
23*	A	0.0100		0.70	0.70			0.30	0.30	0.0150	1.5	0.40	0.60	1.00	1.010	1.20	1.20
24*	A	0.0100	0.20	0.80	0.80			0.20	0.20	0.0300	3.0	0.20	0.20	0.40	1.050	0.80	1.20
25*	A	0.0100		0.70	0.70	0.30			0.30	0.0250	2.5	0.10	0.10	0.20	1.005	7.00	1.00
26*	A	0.0050		0.70	0.70		0.30		0.30	0.0150	3.0	0.30	0.10	0.40	1.010	0.80	5.00

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27*	D	0.0150		0.90	0.90	0.10		0.10	0.0300	2.0	0.20	0.20	0.40	1.010	1.20	1.00
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* Samples with an asterisk are those out of the scope of the invention.
 ** Based on the main component
 *** Per 100 parts by weight of (main component + MgO)

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13 NOV 1997

The resulting mixture was kneaded in a ball mill in a wet process together with a polyvinyl butyral-based binder and an organic solvent, such as ethanol, to prepare a ceramic slurry. The slurry was shaped into a 11 μm thick rectangular green sheet by means of a doctor blade. A conductive paste mainly comprising nickel was screen printed on the ceramic green sheet to form a conductive paste layer one end of which reached the end of the green sheet.

A plurality of the ceramic green sheets were piled up in such a manner that the every other ceramic green sheet had its end with the internal electrode exposed arranged on one side of the resulting laminate. The laminate was heated at 350°C in a nitrogen atmosphere to burn the binder and then calcined at a temperature shown in Table 3 for 2 hours in a reducing atmosphere of $\text{H}_2\text{-N}_2\text{-H}_2\text{O}$ gas having an oxygen partial pressure of 10^9 to 10^{-12} MPa to obtain a ceramic laminate.

The surface of the resulting ceramic laminate was observed under a scanning electron microscope at 1500 magnifications to measure the grain size.

A silver paste containing $\text{B}_2\text{O}_3\text{-Li}_2\text{O-SiO}_2\text{-BaO}$ -based glass frit was applied onto both sides of the ceramic laminate where the internal electrodes were exposed and baked at 600°C in a nitrogen atmosphere to form an external electrode electrically connected to the internal electrodes.

The thus prepared monolithic ceramic capacitor had a width of 1.6 mm, a length of 3.2 mm and a thickness of 1.2 mm. Each dielectric ceramic layer between two internal electrode layers had a thickness of 8 μm . The number of effective dielectric ceramic layers

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13 NOV 1997

was 19. The area of the opposing electrodes was 2.1 mm^2 per side.

The electric characteristics of the condenser were measured. The capacitance (C) and the dielectric loss ($\tan \delta$) were measured with an automatic bridge type meter at 1 kHz, 1 Vrms and 25°C . From the capacitance was calculated the dielectric constant (ϵ). The insulation resistance (R) was measured by applying a direct voltage of 16 V for 2 minutes at 25°C and 125°C with an insulation resistance tester, and the product of the capacitance (C) and the insulation resistance (R), i.e., CR product, was obtained.

Further, capacitance was measured at varying temperatures to determine the percentage difference between capacitances measured at -25°C or 85°C and 20°C to the capacitance at 20°C (percentage change: $\Delta C/C_{20^\circ\text{C}}$), a percentage of a difference between capacitances measured at -55°C or 125°C and 25°C to the capacitance at 25°C (percentage change: $\Delta C/C_{25^\circ\text{C}}$), and the maximum absolute percentage change in capacitance measured in a temperature range of from -55 to 125°C ($|C|_{\text{max}}$).

The duration of the condenser was evaluated by a high-temperature loading test. A direct voltage of 100 V was applied to each of 36 condensers per sample at 150°C , and the insulation resistance (R) was measured with time. The time when the insulation resistance fell to $10^6 \Omega$ or lower was taken as the life duration, and an average duration of life was obtained for each sample.

Furthermore, the condenser was subjected to a high-humidity loading test in which a direct voltage of 16 V was applied to each of 72 condensers per sample

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13 NOV 1987

at 121°C, 2 atm and 100% RH, and the insulation resistance (R) was measured with time. The number of rejects whose insulation resistance (R) fell to $10^6 \Omega$ or lower before 250 hours from the start of the test was counted.

The results of the above measurements are shown in Table 3 below.

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Table 3

Sample No.	Calcining Temp. (°C)	Dielectric Constant (ϵ)	Dielectric Loss ($\tan \delta$) (%)	Percentage Change in Capacitance $\Delta C/C_{25^\circ\text{C}}$ (%)			CR Product (75°C) (MO· μ F)	CR Product (125°C) (MO· μ F)	Average Duration of Life (hr)	Reject Rate in High-Humidity Loading Test	Grain Size (μm)
				-25°	55°C	125°C					
1*	1300	2780	3.0	-4.9	-10.9	12.8	8210	16V	4	0/72	0.79
2*	1300			unmeasurable due to transformation into a semiconductor							
3*	1300	3380	2.1	0.0	-7.8	-9.2	6350	1620	311	0/72	0.74
4*	1280			unmeasurable due to transformation into a semiconductor							
5*	1280	3330	2.3	-0.3	-9.7	-11.0	4120	710	102	0/72	0.73
6*	1280	3380	2.1	0.7	-13.6	-17.0	5310	1310	303	0/72	0.74
7*	1360			unmeasurable due to undercalcination							
8	12801	3360	2.2	0.0	-10.0	-11.4	7170	4820	325	0/72	0.74
9	1300	3110	1.6	-0.1	-7.9	-8.7	6140	2420	437	0/72	0.68
10	1300	3300	1.8	0.2	-7.7	-10.9	7600	3150	426	0/72	0.73
11	1300	3010	1.4	-0.1	-7.0	-8.2	6680	2660	389	0/72	0.60
12	1300	3260	1.7	0.1	-8.3	-9.0	6140	2440	482	0/72	0.76
13	1280	3080	1.5	-0.1	-7.1	-8.8	7850	3080	321	0/72	0.68
14	1300	3170	1.7	-0.3	-6.0	-7.4	6340	2450	419	0/72	0.69

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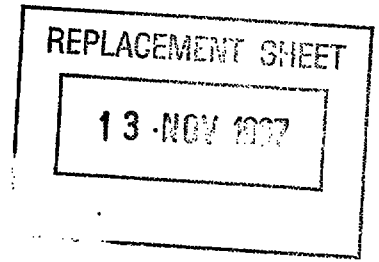
Table 3 - Cont'd.

Sample No.	Calcining Temp. (°C)	Dielectric Constant (ε)	Dielectric Loss (tan δ) (%)	Percentage Change in Capacitance ΔC/C20°C (%)			Percentage Change in Capacitance ΔC/C25°C (%)		CR Product (25°C) (MΩ·μF)	CR Product (125°C) (MΩ·μF)	Average Duration of Life (hr)	Reject Rate in High-Humidity Loading Test	Grain Size (μm)
				-25°	85°		55°C	125°C	max	16V	16V		
15	1300	3300	2.0	0.1	-8.7		0.5	-9.9	9.9	6900	2810	379	0.72
16	1280	3080	1.3	0.8	-7.3		0.1	-12.1	12.1	6980	2810	370	0.71
17*	1360	2260	2.0	0.2	-7.7		-0.5	-9.0	9.0	4990	1560	284	0.64
18*	1300	3010	2.0	0.1	-9.8		-0.6	-16.0	16.0	5880	890	52	0.69
19*	1300	3560	2.3	1.2	-13.0		0.9	-19.5	19.5	6150	1430	298	0.76
20*	1300	3340	2.2	1.6	-15.9		0.9	-18.0	18.0	6700	2030	373	0.72
21*	1300	3200	1.7	0.1	-9.3		-0.1	-11.3	11.3	4580	720	173	0.71
22*	1300	3100	1.5	-0.3	-7.5		-1.2	-8.5	8.5	4650	860	192	0.69
23*	1280	3180	1.8	0.9	-9.7		-0.1	-12.1	12.1	4050	690	183	0.70
24*	1360												0.61
unmeasurable due to undercalcination													
25*	1360	2570	1.1	-0.1	-6.0		-1.0	-7.2	7.2	5070	1600	353	0.66
26*	1260	2310	1.8	0.9	-13.1		0.6	-19.3	19.3	5120	2330	401	0.64
27*	1280	2370	1.6	0.4	-5.3		0.7	-6.1	6.1	6810	2490	498	0.64

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Samples with an asterisk are those out of the scope of the invention.

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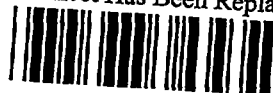
As is apparent from Tables 1 through 3, the monolithic ceramic capacitors according to the present invention have a dielectric constant (ϵ) of not smaller than 3000 and a dielectric loss ($\tan \delta$) of not more than 2.5%, and their percentage change in capacitance with temperature satisfies the B characteristics standard (JIS) between -25°C and 85°C and the X7R characteristics standard (EIA) between -55°C and 125°C. The insulation resistance at 25°C or 125°C, as expressed in terms of CR product, is as high as 6000 MΩ·μF or more or 2000 MΩ·μF or more, respectively. The average duration of life is as long as 300 hours or longer. The ceramic material used in these condensers can be calcined at relatively low temperatures of 1300°C or lower. The grain size of the ceramic is not greater than 1 μm.

In the composition represented by formula $(1-\alpha-\beta)\{\text{BaO}\}_m\cdot\text{TiO}_2+\alpha\{(1-x)\text{M}_2\text{O}_3+x\text{Re}_2\text{O}_3\}+\beta(\text{Mn}_{1-y-z}\text{Ni}_y\text{Co}_z)\text{O}$ (wherein M_2O_3 and Re_2O_3 are as defined above), α should range from about 0.0025 to 0.025 and preferably about 0.006-0.015. If α , the amount of $(\text{M}_2\text{O}_3+\text{Re}_2\text{O}_3)$, is less than about 0.0025 as in sample 1, the dielectric constant ϵ is lower than 3000, the dielectric loss ($\tan \delta$) exceeds 2.5%, the capacity considerably varies with temperature change, and the average duration of life is extremely short.

If α exceeds about 0.025 as in sample 17, the dielectric constant does not exceed 3000, the insulation resistance at 25°C and 125°C is reduced, the average duration of life is short, a high calcining temperature is required, and rejects occur in a high-humidity loading test.

In the above formula, β representing the amount of (Mn, Ni, Co) should range from about 0.0025 to 0.05

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13 NOV 1997

and preferably about 0.005-0.03. If β is less than about 0.0025, the dielectric ceramic is reduced upon calcination in a reducing atmosphere and changes into a semiconductor having a reduced insulation resistance as is observed with sample 2.

If β exceeds about 0.05, the insulation resistance is low, the average duration of life is short, and the variation in capacity with temperature change is large as is observed with sample 18.

The ratio β/α representing the ratio of the amount of (Mn, Ni, Co) to the amount of ($M_2O_3 + Re_2O_3$) should be about 4 or less and preferably about 3 or less. If it exceeds about 4, the variation in capacity with temperature change is large, the insulation resistance at 125°C is lower than 2000 M $\Omega \cdot \mu F$ (in terms of CR product), and the average duration of life is shorter than 300 hours as with sample 19.

x should be more than 0 and not more than about 0.50 and preferably about 0.1-0.3. If x is 0 as in sample 3, the insulation resistance is less than 2000 M $\Omega \cdot \mu F$ (CR product). If x exceeds about 0.5 as in sample 20, the variation in capacity with temperature change is too large to satisfy the B characteristics specified in JIS and the X7R characteristics specified by EIA standards.

m representing the molar ratio of barium titanate should be more than about 1.000 and not more than about 1.035 and preferably about 1.005-1.02. If it is less than about 1.000 the dielectric ceramic material is transformed into a semiconductor as is observed with sample 4. If it is 1.000 as in sample 5, the insulation resistance is low, and the average duration of life is shorter than 300 hours. If the molar ratio m exceeds

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13 NOV 1997

about 1.035, the calcination properties are extremely poor as is observed with sample 24.

$y+z$ in the above formula should be 0 to less than about 1.0, preferably about 0.1-0.5. If $y+z$ is 1.00 (i.e., Mn is absent) as in samples 21, 22 and 23, the insulation resistance is reduced, and the average duration of life is shorter than 300 hours.

The amount of magnesium oxide as a secondary component should range from about 0.5 to 5.0 mol in terms of MgO per 100 mol of the main component and preferably about 0.8-1.5. If it is less than about 0.5 mol as in sample 6, the insulation resistance is reduced, and the variation in capacity with temperature change becomes high. On the other hand, if the amount of MgO exceeds about 5 mol, the calcining temperature must be increased, and the reject rate in a high-humidity loading test is extremely high as with the case of sample 25.

The amount of the $\text{SiO}_2\text{-TiO}_2\text{-MO}$ -based oxide glass should be in a range of from about 0.2 to 3.0 parts by weight per 100 parts by weight of the total weight of the main component and the secondary component, MgO, and preferably about 1-1.5. If it is less than about 0.2 part as in sample 7, the ceramic material suffers from undercalcination. If it exceeds about 3.0 parts as in sample 26, the dielectric constant is low, the insulation resistance at 25°C does not exceed 6000 $\text{M}\Omega\cdot\mu\text{F}$ (CR product), and the variation in capacity with temperature change becomes larger.

The content of alkali metal oxide impurities in barium titanate should be about 0.02% by weight or less and preferably about 0.012. If it exceeds about 0.02% as in sample 27, reduction in dielectric constant results.

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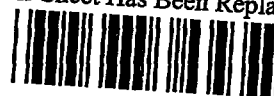
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EXAMPLE 2

SiO₂-TiO₂-MO-based oxide glasses having an average particle size of not greater than 1 μ m and the composition shown in Table 4 below were prepared by heating a raw material mixture at 1200 to 1500°C in the same manner as in Example 1. A hundred moles of a main component represented by compositional formula: $97.5\{\text{BaO}\}_{1.010} \cdot \text{TiO}_2 + 0.8\text{Y}_2\text{O}_3 + 0.2\text{Gd}_2\text{O}_3 + 1.5(\text{Mn}_{0.4}\text{Ni}_{0.2}\text{Co}_{0.4})\text{O}$ (molar ratio) in which barium titanate A shown in Table 1 was used, 1.0 mol of MgO, and 1.0% by weight, based on the total weight of the main component and MgO, of the above oxide glass were compounded to prepare a ceramic material.

** 1 A monolithic ceramic capacitor was produced in the same manner as in Example 1, except for using the above prepared ceramic material. The electrical characteristics of the resulting condenser were evaluated in the same manner as in Example 1. The results obtained are shown in Table 5 below.

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Table 4														
Sample No.	Amount of Oxide Glass Added (wt %)	Components of Oxide Glass										Additive Component (%)		
		Main Components (mol %)												
		SiO ₂	TiO ₂	BaO	CaO	SrO	MgO	ZnO	MnO	Total	Al ₂ O ₃	ZrO ₂		
101	1.0	85	1	1	-	-	-	4	9	14	-	-		
102	1.0	35	51	-	10	-	-	-	4	14	-	-		
103	1.0	30	20	-	30	-	15	4	1	50	-	-		
104	1.0	39	1	20	20	2	-	13	5	60	-	-		
105	1.0	70	10	5	5	-	-	10	-	20	-	-		
106	1.0	45	10	-	-	-	-	15	30	45	-	-		
107	1.0	50	20	10	10	3	7	-	-	30	-	-		
108	1.0	50	30	-	16	-	-	-	4	20	-	-		
109	1.0	35	30	25	10	-	-	-	-	35	-	-		
110	1.0	40	40	10	-	-	-	5	5	20	-	-		
111	1.0	45	22	3	30	-	-	-	-	33	15	-		
112	1.0	45	22	3	30	-	-	-	-	33	10	-		
113*	1.0	65	25	5	5	-	-	-	-	10	-	-		
114*	1.0	25	40	15	-	10	-	5	5	35	-	-		
115*	1.0	30	10	30	25	-	-	5	-	60	-	-		

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Table 4 - Cont'd.													
Components of Oxide Glass													
Sample No.	Amount of Oxide Glass Added (wt %)	Main Components (mol %)										Additive Component (%)	
		SiO ₂	TiO ₂	MO						Total	Al ₂ O ₃	ZrO ₂	
				BaO	CaO	SiO	MgO	ZnO	MnO				
116*	1.0	50	0	35	15	-	-	-	-	50	-	-	-
117*	1.0	45	22	30	-	-	3	-	-	33	25	-	-
118*	1.0	45	22	30	-	3	-	-	-	33	-	15	-
119*	1.0	30	66	10	-	-	-	-	-	10	-	-	-

Samples with an asterisk are those out of the scope of the invention.

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13 NOV 1987

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Table 5

Sample No.	Calcining Temp. (°C)	Dielectric Constant (ε)	Dielectric Loss (tan δ) (%)	Percentage Change in Capacitance ΔC/C20°C (%)			CR Product (25°C) (MΩ·μF)	CR Product (125°C) (MΩ·μF)	Average Duration of Life (hr)	Reject Rate in High-Humidity Loading Test	Grain Size (μm)
				-25°	-85°	Percentage Change in Capacitance ΔC/C25°C (%)					
							55°C	125°C	max	16V	16V
101	1300	3080	1.9	-1.2	-7.2	-2.3	-8.0	8.0	412	0/72	0.71
102	1300	3330	2.1	-1.0	-7.1	-1.6	-7.4	7.4	356	0/72	0.70
103	1300	3260	1.8	-0.9	-8.0	-0.4	-9.9	9.9	379	0/72	0.70
104	1300	3260	1.7	-1.4	-6.5	-1.7	-7.2	7.2	403	0/72	0.70
105	1280	3190	2.1	-0.9	-7.5	-1.5	-8.1	8.1	388	0/72	0.70
106	1280	3250	1.8	-1.3	-6.3	-1.6	-7.4	7.4	358	0/72	0.71
107	1300	3270	1.8	-1.2	-7.9	-1.6	-8.9	8.9	392	0/72	0.71
108	1280	3150	1.5	-0.5	-8.6	-0.1	-10.7	10.7	416	0/72	0.70
109	1280	3410	2.2	-1.1	-7.1	-1.6	-7.4	7.4	491	0/72	0.72
110	1280	3300	2.0	-0.3	-9.3	0.0	-11.3	11.3	338	0/72	0.71
111	1300	3110	1.9	-0.7	-7.8	-1.2	-8.8	8.8	590	0/72	0.70
112	1300	3070	1.8	-0.6	-8.4	-0.8	-12.7	12.7	585	0/72	0.71
113*	1360	2660	2.5	-2.1	-2.3	-2.8	1.5	3.0	36	53/72	0.66

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13 NOV 1997

114*		unmeasurable due to undercalcination										0.61	
Table 5 - Cont'd.													
Sample No.	Calcining Temp. (°C)	Dielectric Constant (ε)	Dielectric Loss (tan δ) (%)	Percentage Change in Capacitance ΔC/C20°C (%)		Percentage Change in Capacitance ΔC/C25°C (%)		CR Product (25°C) (MΩ·μF)	CR Product (125°C) (MΩ·μF)	Average Duration of Life (hr)	Reject Rate in High-Humidity Loading Test	Grain Size (μm)	
				-25°	85°	55°C	125°C						max
115*	1360	unmeasurable due to undercalcination											
116*	1360	3290	2.2	-1.2	-7.5	-1.2	-9.6	9.6	6440	2280	363	72/72	0.61
117*	1360	unmeasurable due to undercalcination											
118*	1360	unmeasurable due to undercalcination											
119*	1360	unmeasurable due to undercalcination											
		unmeasurable due to undercalcination											0.61

Samples with an asterisk are those out of the scope of the invention.

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13 NOV 1997

As is apparent from Tables 4 and 5, the monolithic ceramic capacitors constituted by the dielectric ceramic layers containing SiO_2 - TiO_2 -MO-based oxide glass according to the present invention exhibit a high dielectric constant (ϵ) of 3000 or more, a dielectric loss ($\tan \delta$) of not more than 2.5%, and their percentage change in capacitance with temperature satisfies the B characteristics standard (JIS) between -25°C and 85°C and the X7R characteristics standard (EIA) between -55°C and 125°C . The insulation resistance at 25°C or 125°C , as expressed in terms of CR product, is as high as $6000 \text{ M}\Omega \cdot \mu\text{F}$ or more or $2000 \text{ M}\Omega \cdot \mu\text{F}$ or more, respectively. The average duration of life is as long as 300 hours or longer. No rejects were observed in the high-humidity loading test.

To the contrary, samples 113 to 116 and 119 showed undercalcination or developed rejects in the high-humidity loading test. That is, when the composition of SiO_2 - TiO_2 -MO-based oxide glass is plotted on a triangular diagram of (SiO_2 , TiO_2 , MO) (wherein MO is as defined above), the composition of the oxide glass used in these samples is not in the area surrounded by, or not on, four straight lines connecting four points: A (85,1,14), B (35,51,14), C (30,20,50), and D (39,1,60) (unit: mol%).

As is understood from the results of samples 111 and 112, addition of Al_2O_3 or ZrO_2 to the SiO_2 - TiO_2 -MO-based oxide glass is effective to provide a monolithic ceramic capacitor having an insulation resistance (CR product) of not lower than $7000 \text{ M}\Omega \cdot \mu\text{F}$ at 25°C and not lower than $3000 \text{ M}\Omega \cdot \mu\text{F}$ at 125°C . Note that addition of more than 15 parts by weight of Al_2O_3 or more than 5 parts by weight of ZrO_2 , per 100 parts by weight of the SiO_2 -

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13 NOV 1997

TiO₂-MO-based oxide glass results in extreme reduction in sintering properties.

While the barium titanate powder used in the foregoing Examples is one prepared by an oxalic acid process, barium titanate powder prepared by an alkoxide process or a hydrothermal process can be used as well. In some cases, use of barium titanate powder prepared by an alkoxide process or a hydrothermal process can bring about better characteristics than demonstrated in the above Examples.

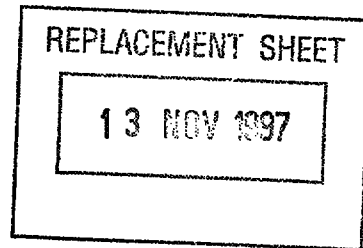
Further, while oxide powders, such as scandium oxide, yttrium oxide, gadolinium oxide, terbium oxide, dysprosium oxide, manganese oxide, cobalt oxide, nickel oxide and magnesium oxide, were used as raw materials, the raw materials for the dielectric ceramic layers are not limited to these oxides. For example, a solution of an alkoxide or an organometallic compound of each metal element can be used as well as long as the resulting ceramic layer has the composition according to the present invention.

While the invention has been described in detail and with reference to specific embodiments thereof, it will be apparent to one skilled in the art that various changes and modifications can be made therein without departing from the spirit and scope thereof.

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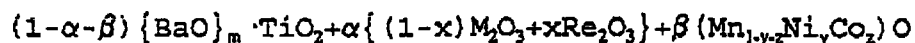


WHAT IS CLAIMED IS:

1. A monolithic ceramic capacitor comprising a laminate of a plurality of dielectric ceramic layers, at least internal electrodes between adjacent dielectric ceramic layers in such a manner that one end of each internal electrode is exposed at different ends of the dielectric ceramic layer alternately, and a pair of external electrodes each electrically connected to different exposed internal electrodes

, in which said dielectric ceramic layers comprise (a) barium titanate having an alkali metal oxide impurity content of not more than about 0.02% by weight, (b) at least one member selected from the group consisting of scandium oxide and yttrium oxide, (c) at least one member selected from the group consisting of gadolinium oxide, terbium oxide and dysprosium oxide, (d) manganese oxide, (e) cobalt oxide and (f) nickel oxide, and is a material containing

(1) 100 mol of a main component represented by the compositional formula:



wherein M_2O_3 represents at least one member selected from the group consisting of Sc_2O_3 and Y_2O_3 ; Re_2O_3 represents at least one member selected from the group consisting of Gd_2O_3 , Tb_2O_3 and Dy_2O_3 ; $0.0025 \leq \alpha \leq 0.025$; $0.0025 \leq \beta \leq 0.05$; $\beta/\alpha \leq 4$; $0 < x \leq 0.50$; $0 \leq y \leq 1.0$; $0 \leq z \leq 1.0$; $0 \leq y+z < 1.0$; and $1.000 < m \leq 1.035$,

(2) about 0.5 to 5.0 mol, in terms of MgO, of magnesium oxide and



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13 NOV 1997

(3) about 0.2 to 3.0 parts by weight, per 100 parts by weight of the total weight of said main component (1) and said magnesium oxide

(2), of SiO_2 - TiO_2 -MO-based oxide glass, wherein MO represents at least one member selected from the group consisting of BaO, CaO, SrO, MgO, ZnO and MnO.

2. A monolithic ceramic capacitor according to claim 1, wherein the internal electrodes are of nickel or a nickel alloy.

3. A monolithic ceramic capacitor according to claim 2, wherein the alkali metal oxide impurity content of not more than about 0.012% by weight; M_2O_3 represents Y_2O_3 ; Re_2O_3 comprises Dy_2O_3 ; $0.006 \leq \alpha \leq 0.015$; $0.005 \leq \beta \leq 0.03$; $\beta/\alpha \leq 3$; $0.1 \leq x \leq 0.3$; $0.1 \leq x \leq 0.3$; $0.1 \leq y \leq 0.2$; $0.1 \leq z \leq 0.5$; $0.1 \leq y+z \leq 0.5$; and $1.005 \leq m \leq 1.02$; the amount of MgO is about 0.8-1.5 mol; the amount of glass is about 1-1.5 parts; and MO comprises CaO.

4. A monolithic ceramic capacitor according to claim 3, wherein the composition of said SiO_2 - TiO_2 -MO-based oxide glass is, when plotted on a triangular mol% diagram of (SiO_2 , TiO_2 , MO)

in the area surrounded by, or on, four straight lines connecting four points: A (85,1,14), B (35,51,14), C (30,20,50), and D (39,1,60)

and contains at least one of Al_2O_3 and ZrO_2 in a total amount of not more than 15 parts by weight per 100 parts by weight of the (SiO_2 , TiO_2 , MO) component,



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13 NOV 1997

provided that the amount of ZrO_2 is not more than 5 parts by weight.

5. A monolithic ceramic capacitor according to claim 4, wherein said external electrodes comprise a sintered layer of an electrically conductive metal powder or an electrically conductive metal powder containing glass frit.

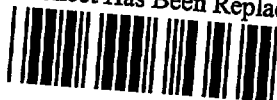
6. A monolithic ceramic capacitor according to claim 4, wherein said external electrodes comprise a first layer made of a sintered layer of an electrically conductive metal powder or an electrically conductive metal layer containing glass frit and a second layer of plating on said first layer.

7. A monolithic ceramic capacitor according to claim 1, wherein the alkali metal oxide impurity content of not more than about 0.012% by weight; M_2O_3 represents Y_2O_3 ; Re_2O_3 comprises Dy_2O_3 ; $0.006 \leq \alpha \leq 0.015$; $0.005 \leq \beta \leq 0.03$; $\beta/\alpha \leq 3$; $0.1 \leq x \leq 0.3$; $0.1 \leq y \leq 0.2$; $0.1 \leq z \leq 0.5$; $0.1 \leq y+z < 0.5$; and $1.005 \leq m \leq 1.02$; the amount of MgO is about 0.8-1.5 mol; the amount of glass is about 1-1.5 parts; and MO comprises CaO .

8. A monolithic ceramic capacitor according to claim 7, wherein the composition of said SiO_2 - TiO_2 - MO -based oxide glass is, when plotted on a triangular mol% diagram of (SiO_2 , TiO_2 , MO) in the area surrounded by, or on, four straight lines connecting four points: A (85,1,14), B (35,51,14), C (30,20,50), and D (39,1,60)



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13 NOV 1997

and contains at least one of Al_2O_3 and ZrO_2 in a total amount of not more than 15 parts by weight per 100 parts by weight of the (SiO_2 , TiO_2 , MO) component, provided that the amount of ZrO_2 is not more than 5 parts by weight.

9. A monolithic ceramic capacitor according to claim 8, wherein said external electrodes comprise a sintered layer of an electrically conductive metal powder or an electrically conductive metal powder containing glass frit.

10. A monolithic ceramic capacitor according to claim 8, wherein said external electrodes comprise a first layer made of a sintered layer of an electrically conductive metal powder or an electrically conductive metal layer containing glass frit and a second layer of plating on said first layer.

11. A monolithic ceramic capacitor according to claim 1, wherein the composition of said SiO_2 - TiO_2 -MO-based oxide glass is, when plotted on a triangular mol% diagram of (SiO_2 , TiO_2 , MO) in the area surrounded by, or on, four straight lines connecting four points: A (85,1,14), B (35,51,14), C (30,20,50), and D (39,1,60) and contains at least one of Al_2O_3 and ZrO_2 in a total amount of not more than 15 parts by weight per 100 parts by weight of the (SiO_2 , TiO_2 , MO) component, provided that the amount of ZrO_2 is not more than 5 parts by weight.

12. A monolithic ceramic capacitor according to claim 11, wherein said external electrodes comprise a sintered layer of an electrically conductive metal

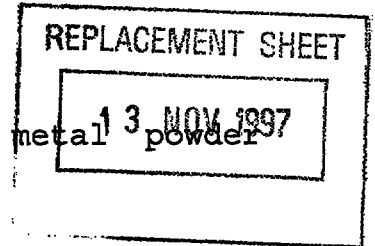


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powder or an electrically conductive metal powder containing glass frit.



13. A monolithic ceramic capacitor according to claim 11, wherein said external electrodes comprise a first layer made of a sintered layer of an electrically conductive metal powder or an electrically conductive metal layer containing glass frit and a second layer of plating on said first layer.

14. A monolithic ceramic capacitor according to claim 1, wherein said external electrodes comprise a sintered layer of an electrically conductive metal powder or an electrically conductive metal powder containing glass frit.

15. A monolithic ceramic capacitor according to claim 1, wherein said external electrodes comprise a first layer made of a sintered layer of an electrically conductive metal powder or an electrically conductive metal layer containing glass frit and a second layer of plating on said first layer.



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MONOLITHIC CERAMIC CAPACITOR

ABSTRACT OF THE DISCLOSURE

A monolithic ceramic capacitor having a plurality of dielectric ceramic layers, internal electrodes, and external electrodes electrically connected to the internal electrode, wherein the dielectric ceramic layers comprise

(a) barium titanate having an alkali metal oxide impurity content of not more than about 0.02% by weight,

(b)

scandium oxide and/or yttrium oxide,

(c)

gadolinium oxide, terbium oxide and/or dysprosium oxide, (d) manganese oxide, (e) cobalt oxide, and (f) nickel oxide, and is a material containing (1) 100

mols represented by the compositional formula:

$(1-\alpha-\beta)\{BaO\}_m \cdot TiO_2 + \alpha\{(1-x)M_2O_3 + xRe_2O_3\} + \beta(Mn_{1-y}Ni_yCo_z)O$

wherein M_2O_3 represents

said (b); Re_2O_3 represents said (c);

$0.0025 \leq \beta \leq 0.05$; $\beta/\alpha \leq 4$; $0 < x \leq 0.50$;

$0 \leq y \leq 1.0$; $0 \leq z \leq 1.0$; $0 \leq y+z < 1.0$; and $1.000 < m \leq 1.035$, (2) about 0.5 to 5.0 mol, in terms of MgO, of magnesium oxide

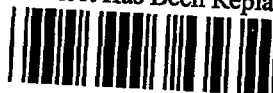
and (3) about 0.2 to 3.0 parts by weight, per 100

pph of components (1) and (2)

, of SiO_2 - TiO_2 -MO-based oxide

glass (wherein MO represents at least one member selected from the group consisting of BaO, CaO, SrO, MgO, ZnO, and

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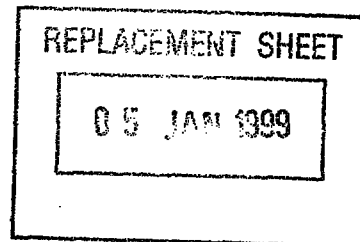
MnO). Said internal electrodes can be nickel or a nickel alloy.

FIG. 4

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MONOLITHIC CERAMIC CAPACITOR

FIELD OF THE INVENTION

This invention relates to a ceramic capacitor, more particularly a monolithic ceramic capacitor having internal electrodes made of nickel or a nickel alloy.

BACKGROUND OF THE INVENTION

A monolithic ceramic capacitor is generally produced according to the following procedures. Dielectric ceramic layers in sheet form having applied thereon an electrode material to serve as an internal electrode are prepared. A ceramic material mainly comprising, e.g., BaTiO_3 , is used as a dielectric ceramic layer. A plurality of the dielectric ceramic layers with the electrode material are piled up and press-bonded under heat into one body. The resulting laminate is calcined at 1250 to 1350°C to obtain a ceramic laminate having internal electrodes. An external electrode is baked onto both sides of the ceramic laminate to make an electrical connection to the internal electrodes and obtain a monolithic ceramic capacitor.

The material for the internal electrodes are required to satisfy the following conditions:

1. To have a melting point at or above the calcining temperature of the ceramic laminate because the internal electrodes and the ceramic laminate are calcined simultaneously.

9 7 JAN 1989

2. To be resistant to oxidation in a high-temperature oxidative atmosphere and be unreactive with the dielectric ceramic layer.

Noble metals, such as platinum, gold, palladium and a silver-palladium alloy, have been used as an electrode material satisfying these requirements. While excellent in performance, these electrode materials are so expensive that the proportion of the electrode material cost reaches 30 to 70% of the entire material cost, which has been the greatest factor of increasing the production cost of monolithic ceramic capacitors.

In addition to noble metals, base metals, such as Ni, Fe, Co, W and Mo, also have a high melting point. However, these base metals are readily oxidized in a high-temperature oxidative atmosphere,

causing them to fail to perform their function as an electrode. Therefore, calcination of the base metal together with dielectric ceramic layers must be carried out in a neutral or reducing atmosphere before they can be used as an internal electrode of a monolithic ceramic capacitor. However, the problem is that a conventional dielectric ceramic material undergoes vigorous reduction into a semiconductor if calcined in a neutral or reducing atmosphere.

Dielectric ceramic materials which have been proposed in order to solve the above problem include a dielectric ceramic material comprising a barium titanate solid solution having a barium site to titanium site ratio in excess of a stoichiometric one (see JP-B-57-42588, the term "JP-B" as used herein means an "examined published Japanese patent application") and a dielectric ceramic material comprising a barium titanate solid

05 JAN 1999

- 3 -

solution having incorporated therein an oxide of a rare earth metal, such as La, Nd, Sm, Dy or Y (see JP-A-61-101459, the term "JP-A" as used herein means an "unexamined published Japanese patent application").

On the other hand, dielectric ceramic materials whose dielectric constant has reduced temperature dependence, such as BaTiO_3 - CaZrO_3 - MnO - MgO system (see JP-A-62-256422) and BaTiO_3 -(Mg, Zn, Sr or Ca) O - B_2O_3 - SiO_2 system (see JP-B-61-14611), have also been proposed.

Use of these dielectric ceramic materials have made it possible to obtain a ceramic laminate that is not transformed into a semiconductor even when calcined in a reducing atmosphere, thereby making it feasible to produce a monolithic ceramic capacitor in which a base metal, such as nickel, is used as an internal electrode.

In recent years, size reduction of electronic components has accelerated rapidly in the development of electronics. Monolithic ceramic capacitors have also showed a remarkable tendency to reduction in size and increase in capacity. There has thus been an increasing demand for a dielectric ceramic material which has a high dielectric constant, shows reduced variation in dielectric constant with temperature change, and is thereby highly reliable.

The dielectric ceramic materials disclosed in JP-B-57-42588 and JP-A-61-101459 exhibit a high dielectric constant but have a large crystal grain size on calcination. When they are applied to a monolithic ceramic capacitor in which each dielectric ceramic layer has a small thickness such as 10 μm or less, the number of crystal grains existing per layer is decreased, resulting in diminished reliability. Besides, these materials undergo considerable variation in dielectric

REPLACEMENT SHEET

05 JAN 1989

constant with temperature change and are not regarded to meet the demands of the market sufficiently.

The dielectric ceramic material disclosed in JP-A-62-256422, on the other hand, exhibits a relatively high dielectric constant and provides on calcination, a ceramic laminate having a small crystal grain size and small variation of dielectric constant with temperature change. However, CaZrO_3 and CaTiO_3 produced on calcination tend to form a secondary phase together with MnO , etc., which has made the resulting monolithic ceramic capacitor less reliable in high temperatures.

The dielectric ceramic material disclosed in JP-B-61-14611 exhibits a dielectric constant of 2000 to 2800, which is disadvantageous for achieving size reduction and capacity increase in a monolithic ceramic capacitor. Moreover, the material fails to fulfill the requirement of X7R characteristics specified by EIA (Electronic Industries Association) standards

that the percentage of change in electrostatic capacity be within a range of $\pm 15\%$ in the temperature range of from -55°C to $+125^\circ\text{C}$.

Although JP-A-5-9066, JP-A-5-9067, and JP-A-5-9068 have proposed ceramic compositions in order to eliminate these problems, the ever-continuing demand for size reduction and capacity increase has been producing a keen demand for dielectric ceramic materials with greater reliability. At the same time, demand for thickness reduction of a ceramic dielectric layer has been getting intenser.

Thus, there has been the necessity for the development of a small-sized and high-capacity monolithic ceramic capacitor having excellent reliability in a high temperature and high humidity environment.

05 JAN 1999

- 5 -

SUMMARY OF THE INVENTION

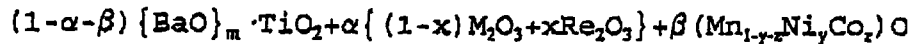
An object of the present invention is to provide an economical, small-sized and high-capacity monolithic ceramic capacitor which has a dielectric constant of 3000 or higher and an insulation resistance as high as 6000 M Ω · μ F or more at room temperature or 2000 M Ω · μ F or more at 125°C, as expressed in terms of the product of capacitance and insulation resistance (CR product), and whose capacity exhibits temperature characteristics satisfying the B characteristics specified by JIS (Japanese Industrial Standards) and the X7R characteristics specified by EIA standards, and which has excellent weathering performance in, for example, loading in high temperature or high humidity.

The present invention provides a monolithic ceramic capacitor having a laminate of a plurality of dielectric ceramic layers, a plurality of internal electrodes each formed between two adjacent dielectric ceramic layers in such a manner that one end of each internal electrode is exposed at one end of the dielectric ceramic layer alternately, and a pair of external electrodes each electrically connected to the plurality of exposed internal electrodes of the laminate, in which the dielectric ceramic layer comprises (a) barium titanate having an alkali metal oxide impurity content of not more than about 0.02% by weight, (b) at least one member selected from the group consisting of scandium oxide and yttrium oxide, (c) at least one member selected from the group consisting of gadolinium oxide terbium oxide and dysprosium oxide, (d) manganese oxide, (e) cobalt oxide and (f) nickel oxide, and is made up of a material containing (1)

05 JAN 1999

- 6 -

100 mol of a main component represented by the compositional formula:



wherein M_2O_3 represents at least one member selected from the group consisting of Sc_2O_3 and Y_2O_3 ; Re_2O_3 represents at least one member selected from the group consisting of Gd_2O_3 , Tb_2O_3 , and Dy_2O_3 ; $0.0025 \leq \alpha \leq 0.025$; $0.0025 \leq \beta \leq 0.05$; $\beta/\alpha \leq 4$; $0 < x \leq 0.50$; $0 \leq y \leq 1.0$; $0 \leq z \leq 1.0$; $0 \leq y+z < 1.0$; and $1.000 < m \leq 1.035$, (2) about 0.5 to 5.0 mol, in terms of MgO , of magnesium oxide as a secondary component, and (3) about 0.2 to 3.0 parts by weight, per 100 parts by weight of the total weight of the main component (1) and the secondary component (2), of SiO_2 - TiO_2 - MO -based oxide glass (wherein MO represents at least one member selected from the group consisting of BaO , CaO , SrO , MgO , ZnO , and MnO), and the internal electrodes are made up of nickel or a nickel alloy.

In a preferred embodiment of the monolithic ceramic capacitor of the present invention, the composition of the SiO_2 - TiO_2 - MO -based oxide glass is, when plotted on a triangular diagram of (SiO_2 , TiO_2 , MO) (wherein MO is as defined above), in the area surrounded by, or on, four straight lines connecting four points: A (85,1,14), B (35,51,14), C (30,20,50), and D (39,1,60) (unit: mol%), and contains at least one of Al_2O_3 and ZrO_2 in a total amount of not more than about 15 parts by weight per 100 parts by weight of the (SiO_2 , TiO_2 , MO) component, provided that the amount of ZrO_2 is not more than about 5 parts by weight.

In another preferred embodiment, the external electrode is made up of a sintered layer of an electrically conductive metal powder which may contain

05 JAN 1999

- 7 -

glass frit. In a still preferred embodiment, the external electrode is composed of a first layer made of a sintered layer of an electrically conductive metal powder which may contain glass frit and a second layer that is formed on the first layer by plating.

BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 is a schematic cross section of a monolithic ceramic capacitor according to one embodiment of the present invention.

Fig. 2 is a schematic plan of a ceramic layer with an internal electrode which is used in the monolithic ceramic capacitor of Fig. 1.

Fig. 3 is a perspective exploded view of the ceramic laminate used in the monolithic ceramic capacitor of Fig. 1.

Fig. 4 is a triangular diagram of (SiO_2 , TiO_2 , MO) showing a preferred range of the composition of SiO_2 - TiO_2 -MO-based oxide glass.

DETAILED DESCRIPTION OF THE INVENTION

In the monolithic ceramic capacitor of the present invention, the dielectric ceramic layers are obtained by calcining a dielectric ceramic material comprising (1) (a) barium titanate, (b) at least one of scandium oxide and yttrium oxide, (c) at least one of gadolinium oxide, terbium oxide and dysprosium oxide, (d) manganese oxide, (e) cobalt oxide and (f) nickel oxide at a ratio shown by the above-described compositional formula having incorporated therein (2) magnesium oxide and (3) SiO_2 - TiO_2 -MO-based oxide glass (wherein MO represents at least one member selected from the group consisting of BaO, CaO, SrO, MgO, ZnO, and

05 JAN 1999

- 8 -

MnO). The dielectric ceramic material can be calcined in a reducing atmosphere without suffering from deterioration of characteristics to provide a highly reliable monolithic ceramic capacitor whose capacity exhibits temperature characteristics satisfying the B characteristics specified by JIS and the X7R characteristics specified by EIA standards, and which exhibits high insulation resistance at room temperature and high temperature.

In the resulting dielectric ceramic laminate, the crystal grains are as small as 1 μm or less so that the grains increase in number per layer. This will secure a sufficient reliability even though the thickness of the dielectric ceramic layer in the laminate is reduced.

The barium titanate constituting the main component (1) contains, as impurities, alkaline earth metal oxides (e.g., SrO and CaO), alkali metal oxides (e.g., Na₂O and K₂O), and other oxides (e.g., Al₂O₃ and SiO₂). Of these impurities, the alkali metal oxides, such as Na₂O and K₂O, have been confirmed to be greatly influential on the electrical characteristics. It was proved that a dielectric constant of not smaller than 3000 can be obtained by using barium titanate having an alkali metal oxide content of not more than about 0.02% by weight and preferably about 0.012% or less.

It has also been found that incorporation of oxide glass mainly comprising SiO₂-TiO₂-MO (wherein MO is at least one member selected from the group consisting of BaO, CaO, SrO, MgO, ZnO, and MnO) into the dielectric ceramic layers brings about improved sintering properties and improved resistance to plating. Further, addition of

05 JAN 1999

Al_2O_3 and/or ZrO_2 to the oxide glass makes it possible to obtain higher insulation resistance.

Dielectric ceramic layers made from the above-described dielectric ceramic material provide a highly reliable, small-sized, and high-capacity monolithic ceramic capacitor, the capacity of which shows reduced variation with temperature. Use of the dielectric ceramic material makes it feasible to use nickel or a nickel alloy as an internal electrode. It is also possible to use nickel or a nickel alloy in combination with a small amount of ceramic powder.

The external electrode is not particularly limited in composition. For example, it can be a sintered layer of a conductive powder of various metals (e.g., Ag, Pd, Ag-Pd, Cu and Cu alloys) or a sintered layer of a mixture of such a conductive metal powder and glass frits of various kinds (e.g., B_2O_3 - Li_2O - SiO_2 - BaO -based glass frits, B_2O_3 - SiO_2 - BaO -based glass frits, Li_2O - SiO_2 - BaO -based glass frits, B_2O_3 - SiO_2 - ZnO -based glass frits). Ceramic powder may be used in a small proportion with the conductive metal powder (and glass frits). It is preferable that the sintered layer is plated with Ni, Cu, an Ni-Cu alloy, etc. The plated layer may further be plated with solder, tin, etc.

A monolithic ceramic capacitor according to one embodiment of the present invention will be described by referring to the accompanying drawings.

Fig. 1 is a schematic cross section of the monolithic ceramic capacitor. Fig. 2 is a schematic plan of a ceramic layer having an internal electrode used in the monolithic ceramic capacitor of this embodiment.

Fig. 3 is a perspective exploded view of the ceramic

05 JAN 1989

laminate used in the monolithic ceramic capacitor of this embodiment.

As shown in Fig. 1, the monolithic ceramic capacitor 1 is of rectangular chip type having a ceramic laminate 3 composed of a plurality of dielectric ceramic layers 2a and 2b, with an internal electrode 4 being interposed between every two ceramic layers. On each side of the ceramic laminate 3 are formed an external electrode 5, a first plating layer 6 formed by plating with nickel, copper, etc., and a second plating layer 7 formed by plating with solder, tin, etc.

The monolithic ceramic capacitor 1 shown in Fig. 1 can be produced as follows.

(1) A main component comprising (a) barium titanate, (b) at least one of scandium oxide and yttrium oxide, (c) at least one of gadolinium oxide, terbium oxide and dysprosium oxide, (d) manganese oxide, (e) cobalt oxide and (f) nickel oxide, (2) magnesium oxide, and (3) SiO_2 - TiO_2 -MO-based oxide glass (wherein MO is as defined above) are compounded together with a binder and a solvent into a slurry and molded to prepare a dielectric ceramic layer 2 (green sheet). An internal electrode 4 of nickel or a nickel alloy is formed on one side of the dielectric ceramic layer 2 by screen printing, vacuum evaporation or plating to obtain a dielectric ceramic layer 2b having an internal electrode 4 as shown in Fig. 2.

A requisite number of the dielectric ceramic layers 2b are piled up and press-bonded in between a pair of dielectric ceramic layers 2a having no internal electrode to obtain a laminate as shown in Fig. 3. The laminate of the dielectric ceramic layers 2a, 2b.

05 JAN 1989

- 11 -

..2b, 2a is calcined in a reducing atmosphere at a prescribed temperature to form a ceramic laminate 3.

An external electrode 5 is then formed on each side of the ceramic laminate 3 to make an electrical connection to the internal electrodes 4. The external electrodes 5 can be made of the same material as used for the internal electrodes 4. In addition, silver, palladium, silver-palladium alloy, copper, copper alloy, etc. are also useful. These metal powders may be used in combination with glass frits, such as B_2O_3 - SiO_2 -BaO-based glass frits or Li_2O - SiO_2 -BaO-based glass frits. The material of the external electrode should be selected appropriately taking into consideration the use of the resulting monolithic ceramic capacitor, the place of use, and the like. The external electrodes 5 can be formed by applying a paste of the metal powder selected to the ceramic laminate 3 (i.e., a calcined laminate) followed by baking. Alternatively, the paste may be applied to the laminate of the green sheets before calcination and baked to form the electrodes 5 and the ceramic laminate 3 simultaneously.

The external electrodes 5 are then plated with nickel, copper, etc. to form a first layer 6. Finally, the first layer 6 is plated with solder, tin, etc. to form a second layer 7, thereby to produce a monolithic ceramic capacitor 1 of the chip type.

As described above, the ceramic material used in the present invention does not undergo reduction and therefore does not change into a semiconductor even if calcined in a reducing atmosphere, which allows use of a base metal (nickel or a nickel alloy) as an electrode material. Further, calcination of the ceramic material can be achieved at a relatively low temperature of not

05 JAN 1998

- 12 -

higher than 1300°C. As a result, both the material cost and the process cost of monolithic ceramic capacitors can be reduced.

The monolithic ceramic capacitor according to the present invention exhibits excellent characteristics, having a dielectric constant of not smaller than 3000, showing reduced variation in dielectric constant with temperature change, having a high insulation resistance, and undergoing no deterioration in characteristics under a high temperature or high humidity condition.

The grain size of the dielectric ceramic material according to the present invention is as small as about 1 μm or less. Therefore, if the thickness of dielectric ceramic layers constituting a monolithic ceramic capacitor is reduced, each layer can have a greater number of crystal grains than in conventional monolithic ceramic capacitors. There is thus provided a highly reliable, small-sized, and yet high-capacity monolithic ceramic capacitor.

The present invention will now be illustrated in greater detail with reference to Examples, but it should be understood that the present invention is not construed as being limited thereto.

EXAMPLE 1

TiCl_4 and $\text{Ba}(\text{NO}_3)_2$, both having varied purity were weighed and treated with oxalic acid to precipitate barium titanyl oxalate ($\text{BaTiO}(\text{C}_2\text{O}_4) \cdot 4\text{H}_2\text{O}$). The precipitate was thermally decomposed at or above 1000°C to synthesize 4 species of barium titanate (BaTiO_3) shown in Table 1 below.

05 JAN 1989

- 13 -

Table 1						
Kind of BaTiO ₃	Content of Impurities (wt%)					Average Particle Size (μ m)
	Alkali Metal Oxide	SrO	CaO	SiO ₂	Al ₂ O ₃	
A	0.003	0.012	0.001	0.010	0.005	0.60
B	0.020	0.010	0.003	0.019	0.008	0.56
C	0.012	0.179	0.018	0.155	0.071	0.72
D	0.062	0.014	0.001	0.019	0.004	0.58

Oxides, carbonates or hydroxides of silicon, titanium, barium, strontium and manganese were weighed and mixed so as to give an SiO₂:TiO₂:BaO:SrO:MnO molar ratio of 0.60:0.25:0.10:0.02:0.03. The mixture was ground and evaporated to dryness to obtain powder. The powder was melted by heating in an aluminum crucible at 1300°C, quenched, and ground to obtain powdered oxide glass having an average particle size of not greater than 1 μ m.

The compositions shown in Table 2 below were compounded from (i) the barium titanate of Table 1, (ii) the powdered oxide glass prepared above, (iii) BaCO₃ serving for adjustment of the Ba/Ti molar ratio of barium titanate and (iv) Sc₂O₃, Y₂O₃, Gd₂O₃, Tb₂O₃, Dy₂O₃, MnCO₃, NiO, Co₂O₃ and MgO, each having a purity of not lower than 99%.

05 JAN 1999

Table 2

Table 2																	
Sample No.	Kind of BaTiO ₃	α	M		1-x	Re			x	β	β/α	y	z	y+z	m	MgO (mol %**)	Amount of Oxide Glass (part by weight***)
			Sc	Y		Gd	Tb	Dy									
1*	A	0.0000								0.00300		0.10	0.30	0.40	1.015	1.00	0.80
2*	A	0.0120		0.80	0.80	0.20			0.20	0.0000					1.010	1.20	1.00
3*	A	0.0100		1.00	1.00				0.00	0.0200	2.0	0.10	0.10	0.20	1.005	0.80	1.00
4*	A	0.0150		0.80	0.80				0.20	0.0300	2.0	0.20	0.20	0.40	0.990	1.00	1.00
5*	A	0.0150		0.70	0.70				0.30	0.0450	3.0	0.20	0.30	0.50	1.000	0.80	1.00
6*	A	0.0200		0.80	0.80				0.20	0.0200	1.0	0.30	0.10	0.40	1.015	0.20	0.80
7*	A	0.0150	0.10	0.70	0.80				0.20	0.0300	2.0	0.10	0.10	0.20	1.005	1.20	0.00
8	A	0.0025		0.80	0.80	0.10			0.20	0.0025	1.0	0.10	0.10	0.20	1.010	1.00	0.20
9	A	0.0250		0.70	0.70				0.30	0.0500	2.0	0.10	0.30	0.40	1.005	0.80	1.20
10	A	0.0060	0.10	0.70	0.80		0.20		0.20	0.0240	4.0	0.10	0.30	0.40	1.010	1.20	1.00
11	B	0.0100	0.50		0.50				0.50	0.0150	1.5	0.20	0.30	0.50	1.020	1.50	1.20
12	C	0.0100		0.90	0.90				0.10	0.0050	0.5	0.00	0.50	0.50	1.010	1.00	1.00
13	A	0.0150		0.80	0.80	0.20			0.20	0.0300	2.0	0.10	0.00	0.10	1.005	0.50	1.00

05 JAN 1999

- 15 -

Table 2 - Cont'd.

Sample No.	Kind of BaTiO ₃	α	M		1-x	Re			x	β	β/α	y	z	y+z	m	MgO (mol %**)	Amount of Oxide Glass (part by weight***)
			M			Re											
			Sc	Y		Gd	Tb	Dy									
14	A	0.0050		0.70	0.70		0.10	0.20	0.30	0.0150	3.0	0.00	0.00	0.00	1.005	5.00	1.20
15	A	0.0100		0.80	0.80	0.10	0.10		0.20	0.0300	3.0	0.10	0.30	0.40	1.035	0.80	1.20
16	A	0.0100		0.80	0.80	0.10	0.05	0.05	0.20	0.0200	2.0	0.10	0.10	0.20	1.010	1.00	3.00

Table 2 - Cont'd.

17*	A	0.0300		0.80	0.80	0.20			0.20	0.0450	1.5	0.10	0.10	0.20	1.010	1.00	1.50
18*	A	0.0200		0.80	0.80			0.20	0.20	0.0700	3.5	0.20	0.40	0.60	1.010	0.80	1.00
19*	A	0.0050		0.70	0.70	0.10		0.20	0.30	0.0300	6.0	0.10	0.10	0.20	1.015	1.00	0.80
20*	A	0.0150		0.20	0.20	0.80			0.80	0.0150	1.0	0.10	0.30	0.40	1.010	1.00	1.20
21*	A	0.0150		0.80	0.80		0.20		0.20	0.0300	2.0	0.00	1.00	1.00	1.010	1.00	1.00
22*	A	0.0050	0.10	0.70	0.80	0.20			0.20	0.0150	3.0	1.00	0.00	1.00	1.010	0.80	1.00
23*	A	0.0100		0.70	0.70			0.30	0.30	0.0150	1.5	0.40	0.60	1.00	1.010	1.20	1.20
24*	A	0.0100	0.20	0.60	0.80			0.20	0.20	0.0300	3.0	0.20	0.20	0.40	1.050	0.80	1.20
25*	A	0.0100		0.70	0.70	0.30			0.30	0.0250	2.5	0.10	0.10	0.20	1.005	7.00	1.00
26*	A	0.0050		0.70	0.70		0.30		0.30	0.0150	3.0	0.30	0.10	0.40	1.010	0.80	5.00

REPLACEMENT SHEET

05 JAN 1999

27*	D	0.0150		0.90	0.90	0.10		0.10	0.0300	2.0	0.20	0.20	0.40	1.010	1.20	1.00
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* Samples with an asterisk are those out of the scope of the invention.
 ** Based on the main component
 *** Per 100 parts by weight of (main component + MgO)

05 JAN 1999

- 17 -

The resulting mixture was kneaded in a ball mill in a wet process together with a polyvinyl butyral-based binder and an organic solvent, such as ethanol, to prepare a ceramic slurry. The slurry was shaped into a 11 μm thick rectangular green sheet by means of a doctor blade. A conductive paste mainly comprising nickel was screen printed on the ceramic green sheet to form a conductive paste layer one end of which reached the end of the green sheet.

A plurality of the ceramic green sheets were piled up in such a manner that the every other ceramic green sheet had its end with the internal electrode exposed arranged on one side of the resulting laminate. The laminate was heated at 350°C in a nitrogen atmosphere to burn the binder and then calcined at a temperature shown in Table 3 for 2 hours in a reducing atmosphere of $\text{H}_2\text{-N}_2\text{-H}_2\text{O}$ gas having an oxygen partial pressure of 10^{-9} to 10^{-12} MPa to obtain a ceramic laminate.

The surface of the resulting ceramic laminate was observed under a scanning electron microscope at 1500 magnifications to measure the grain size.

A silver paste containing $\text{B}_2\text{O}_3\text{-Li}_2\text{O-SiO}_2\text{-BaO-}$ based glass frit was applied onto both sides of the ceramic laminate where the internal electrodes were exposed and baked at 600°C in a nitrogen atmosphere to form an external electrode electrically connected to the internal electrodes.

The thus prepared monolithic ceramic capacitor had a width of 1.6 mm, a length of 3.2 mm and a thickness of 1.2 mm. Each dielectric ceramic layer between two internal electrode layers had a thickness of 8 μm . The number of effective dielectric ceramic layers

05 JAN 1999

- 18 -

was 19. The area of the opposing electrodes was 2.1 mm^2 per side.

The electric characteristics of the condenser were measured. The capacitance (C) and the dielectric loss ($\tan \delta$) were measured with an automatic bridge type meter at 1 kHz, 1 Vrms and 25°C . From the capacitance was calculated the dielectric constant (ϵ). The insulation resistance (R) was measured by applying a direct voltage of 16 V for 2 minutes at 25°C and 125°C with an insulation resistance tester, and the product of the capacitance (C) and the insulation resistance (R), i.e., CR product, was obtained.

Further, capacitance was measured at varying temperatures to determine the percentage difference between capacitances measured at -25°C or 85°C and 20°C to the capacitance at 20°C (percentage change: $\Delta C/C_{20^\circ\text{C}}$), a percentage of a difference between capacitances measured at -55°C or 125°C and 25°C to the capacitance at 25°C (percentage change: $\Delta C/C_{25^\circ\text{C}}$), and the maximum absolute percentage change in capacitance measured in a temperature range of from -55 to 125°C ($|C|_{\text{max}}$).

The duration of the condenser was evaluated by a high-temperature loading test. A direct voltage of 100 V was applied to each of 36 condensers per sample at 150°C , and the insulation resistance (R) was measured with time. The time when the insulation resistance fell to $10^6 \Omega$ or lower was taken as the life duration, and an average duration of life was obtained for each sample.

Furthermore, the condenser was subjected to a high-humidity loading test in which a direct voltage of 16 V was applied to each of 72 condensers per sample

05 JAN 1999

- 19 -

at 121°C, 2 atm and 100% RH, and the insulation resistance (R) was measured with time. The number of rejects whose insulation resistance (R) fell to $10^6 \Omega$ or lower before 250 hours from the start of the test was counted.

The results of the above measurements are shown in Table 3 below.

05 JAN 1999

- 20 -

Table 3

Sample No.	Calcining Temp. (°C)	Dielectric Constant (ϵ)	Dielectric Loss ($\tan \delta$) (%)	Percentage Change in Capacitance $\Delta C/C$ (%)			Percentage Change in Capacitance $\Delta C/C$ (25°C) (%)		CR Product (25°C) (M Ω · μ F)	CR Product (125°C) (M Ω · μ F)	Average Duration of Life (hr)	Reject Rate in High-Humidity Loading Test	Grain Size (μ m)
				-25°	85°	125°C	55°C	max					
1*	1300	2780	3.0	-4.9	17.4	-10.9	12.8	23.2	16V	16V	2010	0/72	0.79
2*	1300			unmeasurable due to transformation into a semiconductor									2.7
3*	1300	3380	2.1	0.0	-7.8	-0.6	-9.2	9.2	6350	1620	311	0/72	0.74
4*	1280			unmeasurable due to transformation into a semiconductor									2.1
5*	1280	3330	2.3	-0.3	-9.7	-0.7	-11.0	11.0	4120	710	102	0/72	0.73
6*	1280	3380	2.1	0.7	-13.6	0.9	-17.0	17.0	5310	1310	303	0/72	0.74
7*	1360			unmeasurable due to undercalcination									0.61
8	12801	3360	2.2	0.0	-10.0	-0.2	-11.4	11.4	7170	4820	325	0/72	0.74
9	1300	3110	1.6	-0.1	-7.9	-0.2	-8.7	8.7	6140	2420	437	0/72	0.68
10	1300	3300	1.8	0.2	-7.7	-0.6	-10.9	1309	7600	3150	426	0/72	0.73
11	1300	3010	1.4	-0.1	-7.0	-0.8	-8.2	8.2	6580	2660	389	0/72	0.60
12	1300	3260	1.7	0.1	-8.3	-0.2	-9.0	9.0	6140	2440	482	0/72	0.76
13	1280	3080	1.5	-0.1	-7.1	-0.5	-8.8	8.8	7850	3080	321	0/72	0.68
14	1300	3170	1.7	-0.3	-6.0	-1.3	-7.4	7.4	6340	2450	419	0/72	0.69

05 JAN 1990

- 21 -

Table 3 - Cont'd.

Sample No.	Calcining Temp. (°C)	Dielectric Constant (ϵ)	Dielectric Loss ($\tan \delta$) (%)	Percentage Change in Capacitance $\Delta C/C$ (%)			CR Product (25°C) (M Ω · μ F)	CR Product (125°C) (M Ω · μ F)	Average Duration of Life (hr)	Reject Rate in High-Humidity Loading Test	Grain Size (μ m)
				-25°	85°	Percentage Change in Capacitance $\Delta C/C$ at 25°C (%)					
							55°C	125°C	max	16V	16V
15	1300	3300	2.0	0.1	-8.7	0.5	-9.9	9.9	379	0/72	0.72
16	1280	3080	1.3	0.8	-7.3	0.1	-12.1	12.1	370	0/72	0.71
17*	1360	2260	2.0	0.2	-7.7	-0.5	-9.0	9.0	284	12/72	0.64
18*	1300	3010	2.0	0.1	-9.8	-0.6	-16.0	16.0	52	0/72	0.69
19*	1300	3560	2.3	1.2	-13.0	0.9	-19.5	19.5	298	0/72	0.76
20*	1300	3340	2.2	1.6	-15.9	0.9	-18.0	18.0	373	0/72	0.72
21*	1300	3200	1.7	0.1	-9.3	-0.1	-11.3	11.3	173	0/72	0.71
22*	1300	3100	1.5	-0.3	-7.5	-1.2	-8.5	8.5	192	0/72	0.69
23*	1280	3180	1.8	0.9	-9.7	-0.1	-12.1	12.1	183	0/72	0.70
24*	1360						unmeasurable due to undercalcination				0.61
25*	1360	2570	1.1	-0.1	-6.0	-1.0	-7.2	7.2	353	48/72	0.66
26*	1260	2310	1.8	0.9	-13.1	0.6	-19.3	19.3	401	0/72	0.64
27*	1280	2370	1.6	0.4	-5.3	0.7	-6.1	6.1	498	0/72	0.64

REPLACEMENT SHEET

05 JAN 1999

Samples with an asterisk are those out of the scope of the invention.

As is apparent from Tables 1 through 3, the monolithic ceramic capacitors according to the present invention have a dielectric constant (ϵ) of not smaller than 3000 and a dielectric loss ($\tan \delta$) of not more than 2.5%, and their percentage change in capacitance with temperature satisfies the B characteristics standard (JIS) between -25°C and 85°C and the X7R characteristics standard (EIA) between -55°C and 125°C . The insulation resistance at 25°C or 125°C , as expressed in terms of CR product, is as high as $6000 \text{ M}\Omega \cdot \mu\text{F}$ or more or $2000 \text{ M}\Omega \cdot \mu\text{F}$ or more, respectively. The average duration of life is as long as 300 hours or longer. The ceramic material used in these condensers can be calcined at relatively low temperatures of 1300°C or lower. The grain size of the ceramic is not greater than $1 \mu\text{m}$.

In the composition represented by formula $(1-\alpha-\beta) \{ \text{BaO} \}_m \cdot \text{TiO}_2 + \alpha \{ (1-x) \text{M}_2\text{O}_3 + x \text{Re}_2\text{O}_3 \} + \beta (\text{Mn}_{1-y-z} \text{Ni}_y \text{Co}_z) \text{O}$ (wherein M_2O_3 and Re_2O_3 are as defined above), α should range from about 0.0025 to 0.025 and preferably about 0.006-0.015. If α , the amount of $(\text{M}_2\text{O}_3 + \text{Re}_2\text{O}_3)$, is less than about 0.0025 as in sample 1, the dielectric constant ϵ is lower than 3000, the dielectric loss ($\tan \delta$) exceeds 2.5%, the capacity considerably varies with temperature change, and the average duration of life is extremely short.

If α exceeds about 0.025 as in sample 17, the dielectric constant does not exceed 3000, the insulation resistance at 25°C and 125°C is reduced, the average duration of life is short, a high calcining temperature is required, and rejects occur in a high-humidity loading test.

In the above formula, β representing the amount of (Mn, Ni, Co) should range from about 0.0025 to 0.05

05 JAN 1999

- 24 -

and preferably about 0.005-0.03. If β is less than about 0.0025, the dielectric ceramic is reduced upon calcination in a reducing atmosphere and changes into a semiconductor having a reduced insulation resistance as is observed with sample 2.

If β exceeds about 0.05, the insulation resistance is low, the average duration of life is short, and the variation in capacity with temperature change is large as is observed with sample 18.

The ratio β/α representing the ratio of the amount of (Mn, Ni, Co) to the amount of ($M_2O_3+Re_2O_3$) should be about 4 or less and preferably about 3 or less. If it exceeds about 4, the variation in capacity with temperature change is large, the insulation resistance at 125°C is lower than 2000 MΩ·μF (in terms of CR product), and the average duration of life is shorter than 300 hours as with sample 19.

x should be more than 0 and not more than about 0.50 and preferably about 0.1-0.3. If x is 0 as in sample 3, the insulation resistance is less than 2000 MΩ·μF (CR product). If x exceeds about 0.5 as in sample 20, the variation in capacity with temperature change is too large to satisfy the B characteristics specified in JIS and the X7R characteristics specified by EIA standards.

m representing the molar ratio of barium titanate should be more than about 1.000 and not more than about 1.035 and preferably about 1.005-1.02. If it is less than about 1.000 the dielectric ceramic material is transformed into a semiconductor as is observed with sample 4. If it is 1.000 as in sample 5, the insulation resistance is low, and the average duration of life is shorter than 300 hours. If the molar ratio m exceeds

65 JAN 1999

- 25 -

about 1.035, the calcination properties are extremely poor as is observed with sample 24.

$y+z$ in the above formula should be 0 to less than about 1.0, preferably about 0.1-0.5. If $y+z$ is 1.00 (i.e., Mn is absent) as in samples 21, 22 and 23, the insulation resistance is reduced, and the average duration of life is shorter than 300 hours.

The amount of magnesium oxide as a secondary component should range from about 0.5 to 5.0 mol in terms of MgO per 100 mol of the main component and preferably about 0.8-1.5. If it is less than about 0.5 mol as in sample 6, the insulation resistance is reduced, and the variation in capacity with temperature change becomes high. On the other hand, if the amount of MgO exceeds about 5 mol, the calcining temperature must be increased, and the reject rate in a high-humidity loading test is extremely high as with the case of sample 25.

The amount of the SiO_2 - TiO_2 -MO-based oxide glass should be in a range of from about 0.2 to 3.0 parts by weight per 100 parts by weight of the total weight of the main component and the secondary component, MgO, and preferably about 1-1.5. If it is less than about 0.2 part as in sample 7, the ceramic material suffers from undercalcination. If it exceeds about 3.0 parts as in sample 26, the dielectric constant is low, the insulation resistance at 25°C does not exceed 6000 $\text{M}\Omega \cdot \mu\text{F}$ (CR product), and the variation in capacity with temperature change becomes larger.

The content of alkali metal oxide impurities in barium titanate should be about 0.02% by weight or less and preferably about 0.012. If it exceeds about 0.02% as in sample 27, reduction in dielectric constant results.

05 JAN 1999

- 26 -

EXAMPLE 2

SiO₂-TiO₂-MO-based oxide glasses having an average particle size of not greater than 1 μ m and the composition shown in Table 4 below were prepared by heating a raw material mixture at 1200 to 1500°C in the same manner as in Example 1. A hundred moles of a main component represented by compositional formula: $97.5\{\text{BaO}\}_{1.010}\cdot\text{TiO}_2 + 0.8\text{Y}_2\text{O}_3 + 0.2\text{Gd}_2\text{O}_3 + 1.5(\text{Mn}_{0.4}\text{Ni}_{0.2}\text{Co}_{0.4})\text{O}$ (molar ratio) in which barium titanate A shown in Table 1 was used, 1.0 mol of MgO, and 1.0% by weight, based on the total weight of the main component and MgO, of the above oxide glass were compounded to prepare a ceramic material.

** 1 A monolithic ceramic capacitor was produced in the same manner as in Example 1, except for using the above prepared ceramic material. The electrical characteristics of the resulting condenser were evaluated in the same manner as in Example 1. The results obtained are shown in Table 5 below.

05 JAN 1999

Table 4

Table 4																
Sample No.	Amount of Oxide Glass Added (wt %)	Components of Oxide Glass														
		Main Components (mol %)										Additive Component (%)				
		MO														
		SiO ₂	TiO ₂	BaO	CaO	SrO	MgO	ZnO	MnO	Total	Al ₂ O ₃	ZrO ₂				
101	1.0	85	1	-	-	-	-	4	9	14	-	-				
102	1.0	35	51	-	10	-	-	-	4	14	-	-				
103	1.0	30	20	-	30	-	15	4	1	50	-	-				
104	1.0	39	1	20	20	2	-	13	5	60	-	-				
105	1.0	70	10	5	5	-	-	10	-	20	-	-				
106	1.0	45	10	-	-	-	-	15	30	45	-	-				
107	1.0	50	20	10	10	3	7	-	-	30	-	-				
108	1.0	50	30	-	16	-	-	-	4	20	-	-				
109	1.0	35	30	25	10	-	-	-	-	35	-	-				
110	1.0	40	40	10	-	-	-	5	5	20	-	-				
111	1.0	45	22	3	30	-	-	-	-	33	15	-				
112	1.0	45	22	3	30	-	-	-	-	33	10	5				
113*	1.0	65	25	5	5	-	-	-	-	10	-	-				
114*	1.0	25	40	15	-	10	-	5	5	35	-	-				
115*	1.0	30	10	30	25	-	-	5	-	60	-	-				

05 JAN 1992

- 28 -

Table 4 - Cont'd.													
Sample No.	Amount of Oxide Glass Added (wt %)	Components of Oxide Glass											
		Main Components (mol %)						MO				Additive Component (%)	
		SiO ₂	TiO ₂	BaO	CaO	SrO	MgO	ZnO	MnO	Total	Al ₂ O ₃	ZrO ₂	
116*	1.0	50	0	35	15	-	-	-	-	50	-	-	
117*	1.0	45	22	30	-	-	3	-	-	33	25	-	
118*	1.0	45	22	30	-	3	-	-	-	33	-	15	
119*	1.0	30	66	10	-	-	-	-	-	10	-	-	

Samples with an asterisk are those out of the scope of the invention.

05 JAN 1999

Table 5

Sample No.	Calcining Temp. (°C)	Dielectric Constant (ε)	Dielectric Loss (tan δ) (%)	Percentage Change in Capacitance ΔC/C20°C (%)			CR Product (25°C) (MΩ·μF)	CR Product (125°C) (MΩ·μF)	Average Duration of Life (hr)	Reject Rate in High-Humidity Loading Test	Grain Size (μm)
				-25°	55°C	125°C					
101	1300	3080	1.9	-1.2	-2.3	-8.0	6520	16V	412	0/72	0.71
102	1300	3330	2.1	-1.0	-1.6	-7.4	6120	2160	356	0/72	0.70
103	1300	3260	1.8	-0.9	-0.4	-9.9	6830	2710	379	0/72	0.70
104	1300	3260	1.7	-1.4	-1.7	-7.2	6580	2500	403	0/72	0.70
105	1280	3190	2.1	-0.9	-1.5	-8.1	6470	2520	388	0/72	0.70
106	1280	3250	1.8	-1.3	-1.6	-7.4	6510	2520	358	0/72	0.71
107	1300	3270	1.8	-1.2	-1.6	-8.9	6330	2320	392	0/72	0.71
108	1280	3150	1.5	-0.5	-0.1	-10.7	6760	2610	416	0/72	0.70
109	1280	3410	2.2	-1.1	-1.6	-7.4	6540	2470	491	0/72	0.72
110	1280	3300	2.0	-0.3	0.0	-11.3	6140	2190	338	0/72	0.71
111	1300	3110	1.9	-0.7	-1.2	-8.8	7970	3460	590	0/72	0.70
112	1300	3070	1.8	-0.6	-0.8	-12.7	7410	3380	585	0/72	0.71
113*	1360	2660	2.5	-2.1	-2.8	1.5	4920	1710	36	53/72	0.66

05 JAN 1999

- 30 -

114*		1360		unmeasurable due to undercalcination										0.61	
Table 5 - Cont'd.															
Sample No.	Calcining Temp. (°C)	Dielectric Constant (ε)	Dielectric Loss (tan δ) (%)	Percentage Change in Capacitance ΔC/C20°C (%)		Percentage Change in Capacitance ΔC/C25°C (%)		CR Product (25°C) (MΩ·μF)	CR Product (125°C) (MΩ·μF)	Average Duration of Life (hr)	Reject Rate in High-Humidity Loading Test	Grain Size (μm)			
				-25°	85°	55°C	125°C						max		
115*	1360														
116*	1360	3290	2.2	-1.2	-7.5	-1.2	-9.6	9.6	6440	2280	72/72	0.61			
117*	1360									363		0.70			
118*	1360											0.61			
119*	1360											0.61			

Samples with an asterisk are those out of the scope of the invention.

85 JAN 1999

As is apparent from Tables 4 and 5, the monolithic ceramic capacitors constituted by the dielectric ceramic layers containing SiO_2 - TiO_2 -MO-based oxide glass according to the present invention exhibit a high dielectric constant (ϵ) of 3000 or more, a dielectric loss ($\tan \delta$) of not more than 2.5%, and their percentage change in capacitance with temperature satisfies the B characteristics standard (JIS) between -25°C and 85°C and the X7R characteristics standard (EIA) between -55°C and 125°C . The insulation resistance at 25°C or 125°C , as expressed in terms of CR product, is as high as $6000 \text{ M}\Omega \cdot \mu\text{F}$ or more or $2000 \text{ M}\Omega \cdot \mu\text{F}$ or more, respectively. The average duration of life is as long as 300 hours or longer. No rejects were observed in the high-humidity loading test.

To the contrary, samples 113 to 116 and 119 showed undercalcination or developed rejects in the high-humidity loading test. That is, when the composition of SiO_2 - TiO_2 -MO-based oxide glass is plotted on a triangular diagram of (SiO_2 , TiO_2 , MO) (wherein MO is as defined above), the composition of the oxide glass used in these samples is not in the area surrounded by, or not on, four straight lines connecting four points: A (85,1,14), B (35,51,14), C (30,20,50), and D (39,1,60) (unit: mol%).

As is understood from the results of samples 111 and 112, addition of Al_2O_3 or ZrO_2 to the SiO_2 - TiO_2 -MO-based oxide glass is effective to provide a monolithic ceramic capacitor having an insulation resistance (CR product) of not lower than $7000 \text{ M}\Omega \cdot \mu\text{F}$ at 25°C and not lower than $3000 \text{ M}\Omega \cdot \mu\text{F}$ at 125°C . Note that addition of more than 15 parts by weight of Al_2O_3 or more than 5 parts by weight of ZrO_2 , per 100 parts by weight of the SiO_2 -

05 JAN 1999

TiO₂-MO-based oxide glass results in extreme reduction in sintering properties.

While the barium titanate powder used in the foregoing Examples is one prepared by an oxalic acid process, barium titanate powder prepared by an alkoxide process or a hydrothermal process can be used as well. In some cases, use of barium titanate powder prepared by an alkoxide process or a hydrothermal process can bring about better characteristics than demonstrated in the above Examples.

Further, while oxide powders, such as scandium oxide, yttrium oxide, gadolinium oxide, terbium oxide, dysprosium oxide, manganese oxide, cobalt oxide, nickel oxide and magnesium oxide, were used as raw materials, the raw materials for the dielectric ceramic layers are not limited to these oxides. For example, a solution of an alkoxide or an organometallic compound of each metal element can be used as well as long as the resulting ceramic layer has the composition according to the present invention.

While the invention has been described in detail and with reference to specific embodiments thereof, it will be apparent to one skilled in the art that various changes and modifications can be made therein without departing from the spirit and scope thereof.

REPLACEMENT SHEET

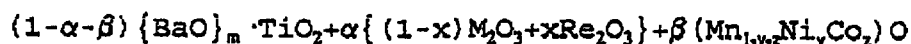
05 JAN 1999

WHAT IS CLAIMED IS:

1. A monolithic ceramic capacitor comprising a laminate of a plurality of dielectric ceramic layers, at least internal electrodes between adjacent dielectric ceramic layers in such a manner that one end of each internal electrode is exposed at different ends of the dielectric ceramic layer alternately, and a pair of external electrodes each electrically connected to different exposed internal electrodes

, in which said dielectric ceramic layers comprise (a) barium titanate having an alkali metal oxide impurity content of not more than about 0.02% by weight, (b) at least one member selected from the group consisting of scandium oxide and yttrium oxide, (c) at least one member selected from the group consisting of gadolinium oxide, terbium oxide and dysprosium oxide, (d) manganese oxide, (e) cobalt oxide and (f) nickel oxide, and is a material containing

(1) 100 mol of a main component represented by the compositional formula:



wherein M_2O_3 represents at least one member selected from the group consisting of Sc_2O_3 and Y_2O_3 ; Re_2O_3 represents at least one member selected from the group consisting of Gd_2O_3 , Tb_2O_3 , and Dy_2O_3 ; $0.0025 \leq \alpha \leq 0.025$; $0.0025 \leq \beta \leq 0.05$; $\beta/\alpha \leq 4$; $0 < x \leq 0.50$; $0 \leq y \leq 1.0$; $0 \leq z \leq 1.0$; $0 \leq y+z < 1.0$; and $1.000 < m \leq 1.035$,

(2) about 0.5 to 5.0 mol, in terms of MgO, of magnesium oxide and



05 JAN 1998

(3) about 0.2 to 3.0 parts by weight, per 100 parts by weight of the total weight of said main component (1) and said magnesium oxide

(2), of SiO_2 - TiO_2 -MO-based oxide glass, wherein MO represents at least one member selected from the group consisting of BaO, CaO, SrO, MgO, ZnO and MnO.

2. A monolithic ceramic capacitor according to claim 1, wherein the internal electrodes are of nickel or a nickel alloy.

3. A monolithic ceramic capacitor according to claim 2, wherein the alkali metal oxide impurity content of not more than about 0.012% by weight; M_2O_3 represents Y_2O_3 ; Re_2O_3 comprises Dy_2O_3 ; $0.006 \leq \alpha \leq 0.015$; $0.005 \leq \beta \leq 0.03$; $\beta/\alpha \leq 3$; $0.1 \leq x \leq 0.3$; $0.1 \leq y \leq 0.2$; $0.1 \leq z \leq 0.5$; $0.1 \leq y+z < 0.5$; and $1.005 \leq m \leq 1.02$; the amount of MgO is about 0.8-1.5 mol; the amount of glass is about 1-1.5 parts; and MO comprises CaO.

4. A monolithic ceramic capacitor according to claim 3, wherein the composition of said SiO_2 - TiO_2 -MO-based oxide glass is, when plotted on a triangular mol% diagram of (SiO_2 , TiO_2 , MO)

in the area surrounded by, or on, four straight lines connecting four points: A (85,1,14), B (35,51,14), C (30,20,50), and D (39,1,60)

and contains at least one of Al_2O_3 and ZrO_2 in a total amount of not more than 15 parts by weight per 100 parts by weight of the (SiO_2 , TiO_2 , MO) component,



05 JAN 1958

provided that the amount of ZrO_2 is not more than 5 parts by weight.

5. A monolithic ceramic capacitor according to claim 4, wherein said external electrodes comprise a sintered layer of an electrically conductive metal powder or an electrically conductive metal powder containing glass frit.

6. A monolithic ceramic capacitor according to claim 4, wherein said external electrodes comprise a first layer made of a sintered layer of an electrically conductive metal powder or an electrically conductive metal layer containing glass frit and a second layer of plating on said first layer.

7. A monolithic ceramic capacitor according to claim 1, wherein the alkali metal oxide impurity content of not more than about 0.012% by weight; M_2O_3 represents Y_2O_3 ; Re_2O_3 comprises Dy_2O_3 ; $0.006 \leq \alpha \leq 0.015$; $0.005 \leq \beta \leq 0.03$; $\beta/\alpha \leq 3$; $0.1 \leq x \leq 0.3$; $0.1 \leq y \leq 0.2$; $0.1 \leq z \leq 0.5$; $0.1 \leq y+z < 0.5$; and $1.005 \leq m \leq 1.02$; the amount of MgO is about 0.8-1.5 mol; the amount of glass is about 1-1.5 parts; and MO comprises CaO .

8. A monolithic ceramic capacitor according to claim 7, wherein the composition of said SiO_2 - TiO_2 - MO -based oxide glass is, when plotted on a triangular mol% diagram of (SiO_2 , TiO_2 , MO) in the area surrounded by, or on, four straight lines connecting four points: A (85,1,14), B (35,51,14), C (30,20,50), and D (39,1,60)



05 JAN 1967

- 36 -

and contains at least one of Al_2O_3 and ZrO_2 in a total amount of not more than 15 parts by weight per 100 parts by weight of the (SiO_2 , TiO_2 , MO) component, provided that the amount of ZrO_2 is not more than 5 parts by weight.

9. A monolithic ceramic capacitor according to claim 8, wherein said external electrodes comprise a sintered layer of an electrically conductive metal powder or an electrically conductive metal powder containing glass frit.

10. A monolithic ceramic capacitor according to claim 8, wherein said external electrodes comprise a first layer made of a sintered layer of an electrically conductive metal powder or an electrically conductive metal layer containing glass frit and a second layer of plating on said first layer.

11. A monolithic ceramic capacitor according to claim 1, wherein the composition of said SiO_2 - TiO_2 - MO -based oxide glass is, when plotted on a triangular mol% diagram of (SiO_2 , TiO_2 , MO) in the area surrounded by, or on, four straight lines connecting four points: A (85,1,14), B (35,51,14), C (30,20,50), and D (39,1,60) and contains at least one of Al_2O_3 and ZrO_2 in a total amount of not more than 15 parts by weight per 100 parts by weight of the (SiO_2 , TiO_2 , MO) component, provided that the amount of ZrO_2 is not more than 5 parts by weight.

12. A monolithic ceramic capacitor according to claim 11, wherein said external electrodes comprise a sintered layer of an electrically conductive metal



05 JAN 1999

- 37 -

powder or an electrically conductive metal powder containing glass frit.

13. A monolithic ceramic capacitor according to claim 11, wherein said external electrodes comprise a first layer made of a sintered layer of an electrically conductive metal powder or an electrically conductive metal layer containing glass frit and a second layer of plating on said first layer.

14. A monolithic ceramic capacitor according to claim 1, wherein said external electrodes comprise a sintered layer of an electrically conductive metal powder or an electrically conductive metal powder containing glass frit.

15. A monolithic ceramic capacitor according to claim 1, wherein said external electrodes comprise a first layer made of a sintered layer of an electrically conductive metal powder or an electrically conductive metal layer containing glass frit and a second layer of plating on said first layer.



05 JAN 1999

MONOLITHIC CERAMIC CAPACITOR

ABSTRACT OF THE DISCLOSURE

A monolithic ceramic capacitor having a plurality of dielectric ceramic layers, internal electrodes, and external electrodes electrically connected to the internal electrode, wherein the dielectric ceramic layers comprise

(a) barium titanate having an alkali metal oxide impurity content of not more than about 0.02% by weight,

(b)

scandium oxide and/or yttrium oxide,

(c)

gadolinium oxide, terbium oxide and/or dysprosium oxide, (d) manganese oxide, (e) cobalt oxide, and (f) nickel oxide, and is a material containing (1) 100

mols represented by the compositional formula:

$(1-\alpha-\beta) \{ \text{BaO} \}_m \cdot \text{TiO}_2 + \alpha \{ (1-x) \text{M}_2\text{O}_3 + x \text{Re}_2\text{O}_3 \} + \beta (\text{Mn}_{1-y-z} \text{Ni}_y \text{Co}_z) \text{O}$

wherein M_2O_3 represents

said (b); Re_2O_3 represents said (c);

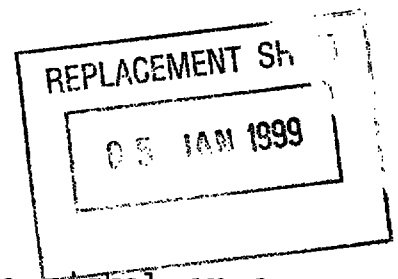
$0.0025 \leq \beta \leq 0.05$; $\beta/\alpha \leq 4$; $0 < x \leq 0.50$;

$0 \leq y \leq 1.0$; $0 \leq z \leq 1.0$; $0 \leq y+z \leq 1.0$; and $1.000 < m \leq 1.035$, (2) about 0.5 to 5.0 mol, in terms of MgO, of magnesium oxide

and (3) about 0.2 to 3.0 parts by weight, per 100

pph of components (1) and (2)

, of SiO_2 - TiO_2 -MO-based oxide glass (wherein MO represents at least one member selected from the group consisting of BaO, CaO, SrO, MgO, ZnO, and



MnO). Said internal electrodes can be nickel or a nickel alloy.

FIG. 4