

PIEZOELECTRIC CERAMIC COMPOSITION AND PIEZOELECTRIC ELEMENT
USING THE PIEZOELECTRIC CERAMIC COMPOSITION

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates to a piezoelectric ceramic composition and a piezoelectric element using the piezoelectric ceramic composition.

2. Description of the Related Art

Conventionally, a piezoelectric ceramic composition containing a lead titanate (PbTiO_3) is known. Since a piezoelectric ceramic composition containing a lead titanate has a low dielectric constant and a small particle size, it is suitable for the use in a high frequency range. Moreover, it has excellent characteristics such as ability in restraining sub-resonance owing to a large piezoelectric anisotropy, durability in use at a high temperature owing to a high Curie point, or the like. Therefore, use of a piezoelectric ceramic containing a lead titanate is required in the field of filters, vibrators, or the like, to be used in a high frequency range. However, a piezoelectric ceramic containing a lead titanate has disadvantages such as difficulty in obtaining a dense sintered compact having a large mechanical strength due to difficulty in sintering, and difficulty in polarization. In order to solve the

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problems, for example, a piezoelectric ceramic composition containing a lead titanate obtained by partially substituting Pb of PbTiO_3 by La and adding a Mn compound such as MnCO_3 , or the like has been used. The piezoelectric ceramic has characteristics such as a good sintering property and capability of a polarization treatment at a high temperature in a high electric field.

However, a problem is involved in that the piezoelectric ceramic has a poor temperature coefficient of the resonance frequency and thus when it is used in a filter or a vibrator, the passing frequency or the oscillating frequency changes drastically according to the temperature. Therefore, it has been difficult to adopt a ceramic containing lead titanate in a filter or a vibrator, which is required to have a high accuracy.

SUMMARY OF THE INVENTION

Accordingly, an object of the present invention is to provide a piezoelectric ceramic composition containing a lead titanate, having excellent temperature stability of the resonance frequency, suitable for the application in a filter, a vibrator, or the like, and a piezoelectric element using the piezoelectric ceramic composition.

In order to achieve the above-mentioned object, a piezoelectric ceramic composition according to the present

invention is represented by the general formula $Pb_{1-1.5x}Nd_x[(In_{1/2}Nb_{1/2})_yTi_{1-y}]O_3$, wherein not less than 0.1% by weight but not more than 3.0% by weight of Mn based on $MnCO_3$ is contained as the sub component in the main component having a composition satisfying $0.02 \leq x \leq 0.16$ and $0.15 \leq y \leq 0.50$. According to the above-mentioned configuration, a piezoelectric ceramic composition having a good temperature coefficient of the resonance frequency can be obtained. Moreover, a piezoelectric element using the piezoelectric ceramic composition with the above-mentioned configuration can restrain the change of the passing frequency, the oscillating frequency, or the like, derived from the temperature.

The amount x of substituting Nd by Pd here is set to be $0.02 \leq x \leq 0.16$ because the sintering property of the ceramic cannot be good and the improving effect of the temperature coefficient of the resonance frequency is small if $x < 0.02$, but the Curie temperature is drastically deteriorated so as not to be durable in a high temperature if $0.16 < x$. The range of y is set to be $0.15 \leq y \leq 0.50$ because the temperature coefficient of the resonance frequency is poor if $y < 0.15$, but the Curie temperature is drastically deteriorated so as not to be durable in a high temperature if $0.50 < y$. The amount of Mn as the sub component is preferably not less than 0.1% by weight but not

more than 3.0% by weight based on MnCO_3 . This is because the mechanical quality coefficient Q_m is small so that it is not suitable for the application in a vibrator, a filter, or the like, with less than 0.1% by weight, but the insulating property of the ceramic is deteriorated so that it cannot be applied with a polarization treatment and thus it cannot be used as a piezoelectric ceramic with more than 3.0% by weight.

BRIEF DESCRIPTION OF THE DRAWING

FIG. 1 is an exploded perspective view showing one embodiment of a piezoelectric element according to the present invention.

DESCRIPTION OF THE PREFERRED EMBODIMENT

Hereinafter, an embodiment of a piezoelectric ceramic composition and a piezoelectric element using the piezoelectric ceramic composition according to the present invention will be explained with reference to the accompanied drawing.

As shown in FIG. 1, a piezoelectric element to be used as a piezoelectric filter comprises a piezoelectric substrate 1, an insulating container 10 accommodating the piezoelectric substrate 1, and a sealing lid 20. The piezoelectric substrate 1 has a substantially rectangular

shape. The piezoelectric substrate 1 is provided with vibrating electrodes 2a, 2b, vibrating electrodes 3a, 3b on the front surface, and vibrating electrodes 2c, 3c on the rear surface. The vibrating electrodes 2a, 3b are connected electrically with lead electrodes 4a, 4b provided on the end parts of the front surface of the piezoelectric substrate 1, respectively. The vibrating electrodes 2b, 3a are connected electrically therewith via a conductor path. The lead electrodes 4a, 4b are arranged on both end parts of the substrate 1, respectively. Furthermore, the vibrating electrodes 2c and 3c are connected electrically via a conductor path provided at the rear center part of the substrate 1. The piezoelectric substrate 1 comprises a ceramic material containing PbTiO_3 . The vibrating electrodes 2a to 3c and the lead electrodes 4a, 4b comprise Ag, Ag-Pd, Ni, Cu, or the like. The piezoelectric substrate 1 generates the thickness longitudinal vibration by the vibrating electrodes 2a, 2b, 2c and the vibrating electrodes 3a, 3b, 3c.

The insulating container 10 has a concave part 10a, with notches 11 provided at both end parts of the concave part 10a. A base 12 is provided at the bottom surface center part of the concave part 10a. The piezoelectric substrate 1 is guided by the notches 11 so as to be accommodated horizontally long sideways for being supported

by the notches 11 and the base 12 without contacting with the bottom surface of the concave part 10a.

The three parts, that is, the parts of the notches 11 and the base 12 of the container 10 are applied with a paste conductive adhesive so that the piezoelectric substrate 1 and the container 10 are fixed and connected electrically via the conductive adhesive. That is, lead electrodes 16, 17, 18 are formed at both end parts and the center part of the container 10 by sputtering, deposition, or the like. The lead electrodes 16, 17 elongate from the notch 11 parts, respectively, and the lead electrode 18 elongates from the base 12 part. The vibrating electrode 2a is connected electrically with the lead electrode 16 of the container 10 via the lead electrode 4a and the conductive adhesive. The vibrating electrode 3b is connected electrically with the lead electrode 17 of the container 10 via the lead electrode 4b and the conductive adhesive. The vibrating electrodes 2c, 3c are connected electrically with the lead electrode 18 of the container 10 via the conductive adhesive.

The sealing lid 20 is provided with conductors 21, 22, 23 at both end part and the center part by sputtering, deposition, or the like. The sealing lid 20 is fixed to the open end face of the container 10 with an adhesive. Accordingly, the piezoelectric substrate 1 is accommodated in the sealed vibrating space provided by the container 10

and the sealing lid 20.

The composition of the piezoelectric substrate 1 will be explained. As the materials of the piezoelectric substrate 1, Pb_3O_4 , Nd_2O_3 , In_2O_3 , Nb_2O_5 , TiO_2 , MnCO_3 were used. Other oxides of Pb, Nd, In, Nb, Ti, Mn, or a compound finally to be an oxide can also be used as a material.

The above-mentioned materials measured so as to have the compositions shown in Tables 1 to 3 were mixed and pulverized by the wet process, and calcined at 750°C to 950°C for 1 to 4 hours. The obtained calcined powders were pulverized with an organic binder, and press-molded with a 1 ton/cm² pressure. The molded products were baked at $1,050^\circ\text{C}$ to $1,250^\circ\text{C}$ for 1 to 4 hours so as to obtain sintered compacts. After forming an electrode, the sintered compacts were polarized by applying a 3 to 5 kV/mm electric field for 10 to 30 minutes in a silicone oil of 100°C , and evaluated. The electric mechanical coupling coefficient k_t (%) at the time of the thickness longitudinal vibration, the mechanical quality coefficient Q_m , the Curie temperature T_c ($^\circ\text{C}$), and the temperature coefficient of the resonance frequency F-TC (ppm/ $^\circ\text{C}$) are shown in Tables 1 to 3. Those marked with * at the specimen number are comparative examples outside the range of the present invention.

Table 1

Specimen number	Nd substitution amount x	In _{1/2} Nb _{1/2} substitution amount y	MnCO ₃ content (% by weight)	k _t (%)	Q _a	T _c (°C)	F-TC (ppm/°C)
* 1	0.10	0.20	0.0	41	110	350	10
* 2	0.10	0.00	0.1	37	650	380	-55
* 3	0.02	0.01	0.1	38	610	400	-49
* 4	0.10	0.01	0.1	39	600	370	-46
* 5	0.16	0.01	0.1	39	590	340	-38
* 6	0.00	0.15	0.1	29	230	390	-62
7	0.02	0.15	0.1	38	540	380	-34
8	0.10	0.15	0.1	40	550	360	-9
9	0.16	0.15	0.1	42	610	300	-5
* 10	0.18	0.15	0.1	41	590	280	12
* 11	0.00	0.20	0.1	30	290	380	-59
12	0.02	0.20	0.1	39	550	370	-33
13	0.10	0.20	0.1	41	540	350	5
14	0.16	0.20	0.1	43	560	290	9
* 15	0.18	0.20	0.1	42	560	280	15
* 16	0.00	0.35	0.1	31	210	360	-44
17	0.02	0.35	0.1	42	590	350	-30
18	0.10	0.35	0.1	41	540	320	10
19	0.16	0.35	0.1	44	550	290	10
* 20	0.18	0.35	0.1	44	520	260	40
21	0.02	0.50	0.1	42	500	330	-10
22	0.10	0.50	0.1	43	480	290	11
23	0.16	0.50	0.1	44	510	290	14
* 24	0.10	0.60	0.1	45	450	280	45

Table 2

Specimen number	Nd substitution amount x	In _{1/2} Nb _{1/2} substitution amount y	MnCO ₃ content (% by weight)	k _t (%)	Q _m	T _c (°C)	F-TC (ppm/°C)
* 25	0.10	0.00	1.0	36	2010	380	-55
* 26	0.02	0.01	1.0	38	2030	400	-50
* 27	0.10	0.01	1.0	38	1980	370	-45
* 28	0.16	0.01	1.0	41	2000	370	-40
* 29	0.00	0.15	3.0	36	1810	400	-66
30	0.02	0.15	3.0	40	2010	380	-33
31	0.10	0.15	3.0	41	1910	360	-12
32	0.16	0.15	3.0	40	1920	300	-10
* 33	0.18	0.15	3.0	39	2000	280	10
* 34	0.00	0.20	1.0	39	1820	390	-60
35	0.02	0.20	1.0	40	2030	370	-30
36	0.10	0.20	1.0	42	1990	350	2
37	0.16	0.20	1.0	42	2040	290	10
* 38	0.18	0.20	1.0	42	2100	280	14
* 39	0.00	0.35	3.0	39	1870	370	-50
40	0.02	0.35	3.0	41	1990	350	-22
41	0.10	0.35	3.0	43	2000	320	8
42	0.16	0.35	3.0	43	1920	290	13
* 43	0.18	0.35	3.0	44	1940	260	20
44	0.02	0.50	1.0	41	1940	330	-21
45	0.10	0.50	1.0	43	1960	290	9
46	0.16	0.50	1.0	45	1960	290	14
* 47	0.10	0.60	1.0	44	1900	260	8

Table 3

Specimen number	Nd substitution amount x	In _{1/2} Nb _{1/2} substitution amount y	MnCO ₃ content (% by weight)	k _t (%)	Q _a	T _c (°C)	F-TC (ppm/°C)
* 48	0.10	0.00	3.0	37	2110	380	-52
* 49	0.02	0.01	3.0	38	2040	400	-49
* 50	0.10	0.01	3.0	39	2060	370	-45
* 51	0.16	0.01	3.0	39	2010	340	-39
* 52	0.00	0.15	3.0	27	1980	390	-66
53	0.02	0.15	3.0	40	2020	380	-36
54	0.10	0.15	3.0	41	2060	360	-10
55	0.16	0.15	3.0	42	2010	300	-8
* 56	0.18	0.15	3.0	44	2050	280	10
* 57	0.00	0.20	3.0	28	2000	380	-62
58	0.02	0.20	3.0	40	1980	370	-35
59	0.10	0.20	3.0	42	1950	350	7
60	0.16	0.20	3.0	43	1980	290	8
* 61	0.18	0.20	3.0	42	2060	270	12
* 62	0.00	0.35	3.0	39	2060	360	-50
63	0.02	0.35	3.0	40	2080	350	-35
64	0.10	0.35	3.0	41	2110	370	10
65	0.16	0.35	3.0	41	2000	290	11
* 66	0.18	0.35	3.0	40	2050	260	16
67	0.02	0.50	3.0	41	2050	330	-25
68	0.10	0.50	3.0	45	2100	290	12
69	0.16	0.50	3.0	44	1980	290	14
* 70	0.10	0.60	3.0	44	1990	260	15

Since the specimen 1 not containing the sub component MnCO_3 , which is outside the range of the present invention, has a 200 or less mechanical quality coefficient Q_m , it is not suitable for the application in a filter, a vibrator, or the like. Moreover, if the sub component MnCO_3 content is increased to 5% by weight, the insulating property of the sintered compact is deteriorated so that the polarization cannot be applied. Therefore, in the present invention, the content of the sub component MnCO_3 is defined to be not less than 0.1% by weight but not more than 3.0% by weight, wherein a preferable mechanical quality coefficient Q_m can be obtained as well as the polarization operation can be conducted easily.

Moreover, as in the specimens 10, 15, 20, 33, 38, 43, 56, 61, and 66, if the amount x of substituting Pb by Nd is increased to 0.18, which is outside the range of the present invention, the Curie temperature is lowered to 280°C or less. If the Curie temperature is 280°C or less, the piezoelectric property of the ceramic is drastically deteriorated by the reflow at the time of mounting an element utilizing a piezoelectric ceramic, such as a filter, a vibrator, or the like, and thus it is not preferable. On the other hand, if the amount x of substituting Pb by Nd is 0.00 (the specimens 6, 11, 16, 21, 34, 39, 52, 57, and 62), the temperature coefficient of the resonance frequency $F\text{-TC}$ is deteriorated

beyond -37 ppm/ $^{\circ}\text{C}$, it is not suitable for the application in a filter, a vibrator, or the like. With the amount x of substituting Pb by Nd in the range of the present invention, $0.02 \leq x \leq 0.16$, a piezoelectric ceramic having a temperature coefficient of the resonance frequency within ± 37 ppm/ $^{\circ}\text{C}$ and a 290°C or more Curie temperature, advantageous in the application in a filter, a vibrator, or the like, can be obtained.

Furthermore, as in the specimens 24, 47 and 70, if the amount y of substituting Ti by $(\text{In}_{1/2}\text{Nb}_{1/2})$ is 0.6, which is outside the range of the present invention, the Curie temperature is lowered to 280°C or less, and thus it is not preferable for the reason mentioned above. However, if the substitution amount by $(\text{In}_{1/2}\text{Nb}_{1/2})$ y is less than 0.15 (the specimens 2 to 5, 25 to 28, and 48 to 51), the temperature coefficient of the resonance frequency F-TC is deteriorated beyond -37 ppm/ $^{\circ}\text{C}$, and thus the amount y of substituting Ti by $(\text{In}_{1/2}\text{Nb}_{1/2})$ needs to be in the range of the present invention, $0.15 \leq y \leq 0.50$ in order to obtain a ceramic having both the temperature stability of the resonance frequency and the heat durability.

A piezoelectric ceramic composition and a piezoelectric element using the piezoelectric ceramic composition according to the present invention are not limited to the above-mentioned embodiment, but can be

modified variously in the range of the gist thereof. In particular, the piezoelectric element is not limited to the above-mentioned embodiment, but can be a vibrator, a trap element, or the like. Moreover, the vibration mode of the piezoelectric substrate can be a thickness sliding vibration mode.

As apparent from the explanation provided above, according to the present invention, a piezoelectric ceramic composition having a good temperature coefficient of the resonance frequency and an excellent heat durability can be obtained. Accordingly, a piezoelectric element, such as a ceramic vibrator, a ceramic filter, or the like, having an excellent temperature stability can be realized without the risk of deteriorating the ability at the time of reflow soldering.

WHAT IS CLAIMED IS:

1. A piezoelectric ceramic composition containing at least Pb, Nd, In, Nb and Ti,

represented by the general formula $Pb_{1-1.5x}Nd_x[(In_{1/2}Nb_{1/2})_yTi_{1-y}]O_3$, wherein not less than 0.1% by weight but not more than 3.0% by weight of Mn based on $MnCO_3$ is contained as the sub component in the main component having a composition satisfying $0.02 \leq x \leq 0.16$ and $0.15 \leq y \leq 0.50$.

2. A piezoelectric element, using the piezoelectric ceramic composition according to claim 1.

