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(73) Patenthaver: **PI Ceramic GmbH, Lindenstrasse, 07589 Lederhose, Tyskland**

(72) Opfinder: **HENNIG, Eberhard, Am Räderweg 18, 07646 Mörsdorf, Tyskland**
KYNAST, Antje, Kochstrasse 16, 04275 Leipzig, Tyskland
TÖPFER, Michael, Fasanengarten 1, 99310 Arnstadt, Tyskland
HOFMANN, Michael, Rodaer Strasse 38, 07806 Neustadt an der Orla, Tyskland

(74) Fuldmægtig i Danmark: **Patrade A/S, Ceresbyen 75, 8000 Århus C, Danmark**

(54) Benævnelse: **Piezokeramisk materiale med reduceret blyindhold**

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Fortsættes ...

A piezoceramic material with reduced lead content

Description

The invention relates to a piezoceramic material with reduced lead content, based on potassium sodium niobate (PSN) of a basic composition according to the preamble of claim 1.

The current prior art in the production of piezoceramic materials is characterized by a radical change with respect to the desired switch to lead-free or lead-reduced products. As a result, measures for reducing the use of especially hazardous substances such as a lead in electrical and electronic devices is demanded in the Directive 2011/65/EU (RoHS2). Accordingly, substances with a lead content of greater than 0.1% by weight in the homogeneous material are subject to limitations for example and may only be marketed with special approval. Alternatives to the starting materials which are more environmentally friendly must still show the same performance features and similar parameters as the current lead-containing variants. Currently, lead zirconate titanate (PZT) is the base piezoceramic material that is used most frequently when rapidly switching piezoelectric applications in the motor vehicle area or sensors are concerned.

It was already proposed to replace PZT by potassium sodium niobate (PSN). Especially the complex modification of the PSN materials with lithium, tantalum and antimony ("Lead-free piezoceramics", Saito et al.; Letters to Nature, 2004) has the potential to represent alternatives to PZT.

EP1382588A1 thus describes a lead-free piezoceramic composition with a main component of the general formula $\{L_{ix}(K_{1-y}Nay)_{1-x}\}$ $(Nb_{1-z-w}Ta_zSb_w)O_3$ and at least one metallic element selected from (1) palladium, silver, gold, ruthenium, rhodium, rhenium, osmium, iridium and platinum, or (2) nickel, iron, manganese, copper, zinc, or (3) magnesium, calcium, strontium and barium as the additional element.

DE 102007013874A1 describes a multilayer piezoelectric element which comprises a plurality of lead-free piezoelectric layers, which contain an oxide having an alkali metal element especially in form of sodium, potassium or lithium and containing niobium or bismuth.

EP2104152A2 describes a piezoelectric element which contains a lead-free piezoelectric ceramic. The components $KNbO_3$ and $BaTiO_3$ are mentioned as the main components of the piezoelectric ceramic. The piezoelectric ceramics have the general formula $xKNbO_3$-(1-x)$BaTiO_3$, wherein x lies between 0.5 and 0.9.

Despite intensive research and development in the past 10 years it has not been possible until now to produce these promising lead-free materials on an industrial scale. The critical moment has proven to be that the desired properties are only achieved in a very narrow sintering interval of 10 to 20 K. Different approaches are described in the prior art to solve this problem. On the one hand, the sintering behaviour is to be improved in particular by further (lead-free) additions.

EP1876155A1, EP1876156A1 and DE112006003755B4 are aimed at broadening the sintering interval of a PSN material on the basis of (K1-a-bNaaLib)m(Nb1-c-dTacSbd)O3 with $0 \leq a \leq 0.9$, $0 \leq b \leq 0.3$, $0 \leq a+b \leq 0.9$, $0 \leq c \leq 0.5$, $0 \leq d \leq 0.1$, $0.7 \leq m \leq 1.3$ by adding perovskite oxides or oxide complexes and further oxides.

EP 1702906A1 describes a piezoceramic material, in which a ceramic basic composition is modified by the addition of alkaline earth metal niobate for example.

On the other hand, alternative sintering methods such as hot pressing, spark plasma sintering (Li et al.; J. Am. Ceram. Soc., 96 [12] 3677-3696 (2013)) or two-step sintering with heating rates of 10 K/min (Pang et al.; Ceramics International, 38 (2012) 2521 – 2527) have been proposed. These methods are not suitable for cost-effective mass production or cannot be implemented on an industrial scale due to the thermal inertia of great sintering volumes.

It is therefore an object of the invention, based on the above information, to provide a piezoceramic material on the basis of potassium sodium niobate (PSN), which in combination with reduced lead content has a sufficiently great expansion for the application in the region of the multilayer actuators and which has a broad sintering interval which in comparison with known lead-free PSN-based materials can be handled well on an industrial scale and therefore can be processed with conventional sintering methods.

The object of the invention is achieved by a piezoceramic material according to the combination of features according to claim 1, and a method for producing such a material according to claim 12. A piezoelectric multilayer actuator on the basis of a material according to the definition as set out in claim 13 is further in accordance with the invention. The use of a mixture of Pb, Nb and optionally Ag in a piezoceramic material on the basis of potassium sodium niobate (PSN) for increasing the sintering interval is also according to the invention.

A lead-free piezoceramic material on the basis of potassium sodium niobate (PSN) of the basic composition

$(K_xNa_yLi_{1-x-y})a\ (Mn_uTa_vSb_wNb_{1-u-v-w})O_3$, with
$0<x<1$ y; $0<y<1$; $0<u<0.01$; $0<v<0.3$; $0\leq w<0.2$
$0.95<a<1.05$; $x+y \leq 1$;

is assumed.

In accordance with the invention, the addition of a mixture of Pb, Nb and Ag occurs as follows:
k% by weight Pb + l% by weight Nb + m% by weight Ag
with
$0<k<0.5$; $0<l<1$; $0\leq m<1$.

The specifications k, l and m relate to percent by weight of the respective component relating to the total mass of the piezoceramic material.

The piezoceramic material in accordance with the invention therefore has the following basic composition:
$(K_xNa_yLi_{1-x-y})a\ (Mn_uTa_vSb_wNb_{1-u-v-w})O_3$, with
$0<x<1$ y; $0<y<1$; $0<u<0.01$; $0<v<0.3$; $0\leq w<0.2$ and

$0.95<a<1.05$; $x+y \leq 1$;
and is characterized in that it contains a further component in addition to the basic composition which comprises Pb, Nb and optionally Ag, wherein the weight fractions of Pb, Nb and Ag are selected as follows relating to the total weight of the piezoceramic material:
k% by weight Pb + l% by weight Nb + m% by weight Ag
with
$0<k<0.5$; $0<l<1$; $0\leq m<1$.

In a preferred embodiment, the quantity of added Pb is selected in such a way that it is $0.001<k\leq 0.2$.

In a further preferred embodiment, the quantity of added Nb is selected in such a way that it is $0<l\leq 0.179$.

Especially good results were achieved if the ratio of added Pb to added Nb is selected in such a way that $0.001<k\leq 0.2$ and $0<l\leq 0.179$.

It was recognised that especially advantageous results can be achieved if the quantity of added Pb is selected in such a way that $0.001<k\leq 0.1$.

It was further recognised that especially good results are achieved if the quantity of added Nb is selected in such a way that $0.022<l\leq 0.09$.

The quantities of added Pb and Nb are selected especially preferably in such a way that $0.001<k\leq 0.1$ and $0.022<l\leq 0.09$.

Experimental examinations have further shown that the object of the invention can also be achieved when the further component additionally comprises Mn next to Pb and Nb and optionally Ag. Especially good results are achieved if the further component comprises k% by weight Pb, l% by weight Nb, and n% by weight Mn, wherein the ratio of n:l lies in the range of 0.05 to 0.15:0.30.

It has proven to be especially preferable that the ratio of Pb to Mn to Nb is selected in such a way that k:n:l lies at 1:0.09:0.30.

It was recognised that the piezoceramic materials have a sintering interval in the range of >20 K, especially in the range of 30 K to 40 K.

The piezoceramic material with reduced lead content is carried out by the steps of producing a calcinate of the basic composition and the addition of the sintering aid mixture. The addition of the sintering aid mixture, which comprises Pb, Nb and optionally Ag and optionally Mn, can occur especially during fine grinding.

The further processing is realised in the known manner, including sintering in normal atmosphere.

The invention thus also relates to a method for producing a piezoceramic material with reduced lead content, characterized by the following steps:

- producing a raw material mixture of the basic composition;
- producing a calcinate of the basic composition;
- fine grinding of the calcinate;
- producing a granulate especially by spray granulation or producing a casting slurry for the multilayer or “co-firing” process;
- further processing in the known manner, including sintering in normal atmosphere.

The “co-firing” process within the terms of the present invention shall be understood as an especially innovative production method in which films made of a piezoceramic material are cast at first and are subsequently provided with electrodes still in the green state. A piezo element is laminated from many individual films and subsequently sintered jointly with the inner electrodes in a single process step, as described for example in DE10234787C1.

A piezoceramic multilayer actuator on the basis of the piezoceramic material according to the teachings of claim 13 is according to the invention.

The invention also relates to the use of a mixture of Pb, Nb and optionally Ag in a piezoceramic material on the basis of potassium sodium niobate (PSN) of the basic composition
$(K_xNa_yLi_{1-x-y})a\ (Mn_uTa_vSb_wNb_{1-u-v-w})O_3$, with
$0<x<1$ y; $0<y<1$; $0<u<0.01$; $0<v<0.3$; $0\leq w<0.2$ and
$0.95<a<1.05$; $x+y \leq 1$;
for increasing the sintering interval of the piezoceramic material, wherein the addition of a mixture of Pb and Nb and optionally Ag occurs in such a way that the content of added Pb, Nb and Ag in percent by weight relating to the entire piezoceramic material is as follows:

k% by weight Pb + l% by weight Nb + m% by weight Ag
with
$0<k<0.5$; $0<l<1$; $0\leq m<1$.

In a preferred embodiment, the quantity of added Pb is selected in such a way that it is $0.001<k\leq 0.2$.

In a further preferred embodiment, the quantity of added Nb is selected in such a way that $0<l\leq 0.179$.

Especially good results were achieved if the ratio of added Pb to added Nb was selected in such a way that $0.001<k\leq 0.2$ and $0<l\leq 0.179$.

It was recognised that especially advantageous results can be achieved if the quantity of added Pb is selected in such a way that $0.001<k\leq 0.1$.

It was further recognised that especially good results can be achieved if the quantity of added Nb is selected in such a way that $0.022<l\leq 0.09$.

Especially preferably, the quantities of added Pb and Nb are selected in such a way that $0.001<k\leq 0.1$ and $0.022<l\leq 0.09$.

Experimental examinations have further shown that the object of the invention can also be achieved when the further component additionally comprises Mn next to Pb and Nb and optionally Ag. Especially good results are achieved if the further component comprises k% by weight Pb, l% by weight Nb, and n% by weight Mn, wherein the ratio of n:l lies in the range of 0.05 to 0.15:0.30.

It has proven to be especially preferable that the ratio of Pb to Mn to Nb is selected in such a way that k:n:l lies at 1:0.09:0.30.

It was surprisingly recognised by the addition of the sintering aids Pb, Nb and optinally Ag and optionally Mn that on the one hand the high insulating resistance and the strain capability of the basic composition is maintained. On the other hand, a broadening of the sintering interval is obtained to ranges between 30 K and 40 K. The addition of Pb and Nb can occur as a nominal compound in form of lead metaniobate, wherein the added quantity of the sintering aid is selected in such a way that the lead content lies in the range of 0.05 % by weight to 0.2 % by weight. The lead content lies at a maximum of 0.1 % by weight in an especially preferred way, relating to the entire piezoceramic material.

The drawings are used for explaining the results of the examinations of different materials on the basis of PSN in accordance with the invention.

Fig. 1 describes the general technological sequence of sample production. “*” relates to such technological steps in which the described addition of Pb and Nb and optionally Ag and optionally Mn can occur.

Fig. 2 shows in comparison the typical temperature dependence of the unipolar strain of the embodiments 1 (prior art) and 8 at a triggering field strength of 2 kV/mm.

Fig. 3 shows in comparison the typical temperature dependence of the specific insulation resistance of the embodiments 1 (prior art) and 8.

Fig. 4a shows the unipolar strain hysteresis and Fig. 4b the sample current in the temperature range of room temperature up to 175°C for embodiment 1.

Fig. 5a shows the unipolar strain hysteresis and Fig. 5b the sample current in the temperature range of room temperature up to 175°C for embodiment 7.

Fig. 6a shows the unipolar strain hysteresis and Fig. 6b the sample current in the temperature range of room temperature up to 175°C for embodiment 8.

Examples

The measurement results mentioned below relate to the basic system $(K_xNa_yLi_{1-x-y})a\ (Mn_uTa_vSb_wNb_{1-u-v-w})O_3$

The mixture of the raw materials and the fine grinding of the calcinate respectively occurred in an agitator bead mill.

The additions of Pb and Nb and optionally Mn occurred in the following technological steps:

Example 1-7: fine grinding
Example 8: addition during spray granulation

The addition of Pb and Nb occurred in the examples 2 and 3 as an oxide mixture (M) and in the examples 4, 5 and 8 as a preformed calcinate (K). The addition of Pb, Nb and Mn occurred in the examples 6 and 7 as an oxide mixture (M).

The parameters used for the evaluation are summarised in Table 1.

Column	Parameter
1	Addition of Pb in percent by weight
2	Addition of Nb in percent by weight
3	Addition as an oxide mixture (M) or calcinate (K)
4	Sintering temperature
5	Sintering interval
6	Dielectric constant

7	Dielectric loss factor
8	Specific insulation resistance (room temperature)
9	Specific insulation resistance (150°C)
10	Induced strain (room temperature)
11	Sample current (room temperature)
12	Measuring field strength
13	Maximum induced strain (room temperature – 150°C)
14	Temperature of maximum strain
15	Induced strain (150°C)

The specific insulation resistance ρ_{is} is determined at 50 V at poled samples at temperature increase from room temperature to 150°C.

The electromechanical strain S_3 is determined by means of laser interferometer at 2 kV/mm. The measuring field strength is stated in column 12 for samples which as a result of increased conductivity could not be measured at 2 kV/mm.

The sintering interval shall be understood as the range bounded by two temperature specifications, within which the required properties of the ceramic are achieved during burning of the material. They are defined as follows:

tan δ:	$\leq 50\ 10^{-3}$
S3 (RT):	$<0.6\ 10^{-3}$
E_{max}:	≥ 2 kV/mm

The following embodiments show the behaviour of the prior art (example 1) and the compositions produced in accordance with the invention (examples 2 to 8). The samples were produced according to the flowchart (Fig. 1).

The results of the examinations are documented in Table 2.

Embodiment 1:

Composition

$(K_{0.44}Na_{0.52}Li_{0.04})0.998\ (Mn_{0.005}[Ta_{0.10}Sb_{0.06}Nb_{0.84}]_{0.995})O_3$

This composition corresponds to the prior art with a sintering interval of ≤ 20 K.

Embodiment 2:

Composition:
$(K_{0.44}Na_{0.52}Li_{0.04})0.998\ (Mn_{0.005}[Ta_{0.10}Sb_{0.06}Nb_{0.84}]_{0.995})O_3$
+0.1% by weight Pb + 0.09% by weight Nb,
added as an oxide mixture. This composition in accordance with the invention shows a broadening of the sintering interval to 30 K.

Embodiment 3:

Composition:
$(K_{0.44}Na_{0.52}Li_{0.04})0.998\ (Mn_{0.005}[Ta_{0.10}Sb_{0.06}Nb_{0.84}]_{0.995})O_3$
+0.2% by weight Pb + 0.179% by weight Nb,
added as an oxide mixture. This composition in accordance with the invention shows a broadening of the sintering interval to 30 K.

Embodiment 4:

Composition:
$(K_{0.44}Na_{0.52}Li_{0.04})0.998\ (Mn_{0.005}[Ta_{0.10}Sb_{0.06}Nb_{0.84}]_{0.995})O_3$
+0.1% by weight Pb + 0.09% by weight Nb,
added as a preformed calcinate. This composition in accordance with the invention shows a broadening of the sintering interval to 30 K.

Embodiment 5:

Composition:
$(K_{0.44}Na_{0.52}Li_{0.04})0.998\ (Mn_{0.005}[Ta_{0.10}Sb_{0.06}Nb_{0.84}]_{0.995})O_3$
+0.2% by weight Pb + 0.179% by weight Nb,
added as a preformed calcinate. This composition in accordance with the invention shows a broadening of the sintering interval to 30 K.

Embodiment 6:

Composition:
$(K_{0.44}Na_{0.52}Li_{0.04})0.998\ (Mn_{0.005}[Ta_{0.10}Sb_{0.06}Nb_{0.84}]_{0.995})O_3$
+0.1% by weight Pb + 0.022% by weight Nb + 0.013% by weight Mn,
added as an oxide mixture. This composition shows no broadening of the sintering interval.

Embodiment 7:

Composition:
$(K_{0.44}Na_{0.52}Li_{0.04})0.998\ (Mn_{0.005}[Ta_{0.10}Sb_{0.06}Nb_{0.84}]_{0.995})O_3$
+0.1% by weight Pb + 0.03% by weight Nb + 0.009% by weight Mn,
added as an oxide mixture. This composition in accordance with the invention shows a broadening of the sintering interval to 40 K.

Embodiment 8:

Composition:
$(K_{0.44}Na_{0.52}Li_{0.04})0.998\ (Mn_{0.005}[Ta_{0.10}Sb_{0.06}Nb_{0.84}]_{0.995})O_3$
+0.1% by weight Pb + 0.09% by weight Nb,
added as a preformed calcinate. This composition in accordance with the invention shows a broadening of the sintering interval to 40 K. In this embodiment, processing of the material occurred continuously on an industrial scale and the addition of Pb and Nb occurred during spray granulation.

The high insulation resistance is surprisingly maintained in the modification in accordance with the invention of the composition
$(K_{0.44}Na_{0.52}Li_{0.04})0.998\ (Mn_{0.005}[Ta_{0.10}Sb_{0.06}Nb_{0.84}]_{0.995})O_3$
by Pb and Nb and optionally Mn.

Nr.	Addition			T_{sint}	ΔT_{sint}	$\varepsilon^T_{33}/\varepsilon_0$	tanδ	ρ_{is}	ρ_{is}	S_3	I	at E_{max}	$S_{3,max}$	$T(S_{3,max})$	S_3
	% by wt.	% by wt.		°C	K		10^{-3}	Ωm	Ωm	10^{-3}	A	kV/mm	10^{-3}	°C	10^{-3}
	Pb	Nb				RT	RT	RT	150°C	RT	RT				150°C
1	0	0,000		1090		1210	41,9	2,8E+09	7,2E+07	0,30	2,3E-06	1,4			
1	0	0,000		1100		1340	40,4	1,6E+09	5,6E+07	0,47	2,4E-06	2,0			
1	0	0,000		**1110**		1300	19,6	3,5E+10	2,6E+08	0,78	1,7E-06	2,0	0,86	50	0,49
1	0	0,000		**1130**	20	1170	26,3	2,8E+09	2,0E+08	0,74	2,1E-06	2,0			
1	0	0,000		1140		980	57,7	4,6E+09	3,3E+08	0,60	2,0E-06	1,5			
2	0,1	0,090	M	1100		1390	77,1			0,34	2,5E-06	1,5			
2	0,1	0,090	M	**1110**		1330	24,1	9,9E+09	1,3E+08	0,74	1,6E-06	2,0			
2	0,1	0,090	M	**1130**		1270	36,2			0,72	1,6E-06	2,0			
2	0,1	0,090	M	**1140**	30	1180	46,2	4,0E+09	7,8E+07	0,67	2,9E-06	2,0			
2	0,1	0,090	M	1150		1220	206,2								
3	0,2	0,179	M	1100		1420	57,4			0,53	2,5E-06	2,0			
3	0,2	0,179	M	**1110**		1620	20,1			0,75	1,8E-06	2,0			
3	0,2	0,179	M	**1130**		1350	24,8	2,3E+10	2,3E+08	0,75	1,6E-06	2,0	0,83	50	0,48
3	0,2	0,179	M	**1140**	30	1350	32,3			0,74	1,5E-06	2,0			
3	0,2	0,179	M	1150		1220	61,6			0,46	6,5E-05	1,5			
4	0,1	0,090	K	1100		1380	75,9			0,39	2,7E-06	1,5			
4	0,1	0,090	K	**1110**		1420	24,0			0,76	1,7E-06	2,0			
4	0,1	0,090	K	**1130**		1350	24,7	1,9E+10	1,5E+08	0,76	1,6E-06	2,0			
4	0,1	0,090	K	**1140**	30	1240	42,7			0,66	2,0E-05	2,0			
4	0,1	0,090	K	1150		1290	186,1								
5	0,2	0,179	K	1100		1420	55,1			0,55	2,6E-06	2,0			
5	0,2	0,179	K	**1110**		1450	19,5			0,79	1,7E-06	2,0			
5	0,2	0,179	K	**1130**		1300	35,5	2,0E+10	1,6E+08	0,69	1,7E-06	2,0	0,81	50	0,49
5	0,2	0,179	K	**1140**	30	1410	31,2			0,72	1,5E-06	2,0			
5	0,2	0,179	K	1150		1190	64,6			0,45	4,6E-05	1,5			
6	0,1	0,022	M	1090		1480	31,9	1,7E+09	5,7E+07	0,57	1,9E-06	2,0			
6	0,1	0,022	M	**1110**		1420	22,4	2,1E+10	2,0E+08	0,74	1,5E-06	2,0	0,82	50	0,50
6	0,1	0,022	M	**1130**	20	1310	25,6	5,6E+09	6,4E+07	0,72	2,1E-06	2,0			
6	0,1	0,022	M	1140		1080	143,0	8,2E+08	5,8E+06						
7	0,1	0,030	M	**1090**		1440	32,5			0,61	2,0E-06	2,0			
7	0,1	0,030	M	**1100**		1580	27,4	5,8E+09	1,5E+08	0,82	2,0E-06	2,0			
7	0,1	0,030	M	**1110**		1570	22,0	3,7E+10	1,9E+08	0,73	1,7E-06	2,0	0,75	60	0,50
7	0,1	0,030	M	**1130**	40	1340	21,5	1,1E+10	1,2E+08	0,73	1,9E-06	2,0			
7	0,1	0,030	M	1140		1040	138,0	6,9E+08	7,3E+06						
8	0,1	0,090	K	1070		1090	29,5	6,3E+08	1,7E+08	0,52	1,6E-06	2,0	0,62	60	0,41
8	0,1	0,090	K	**1080**		1160	30,3	2,3E+09	1,3E+08	0,62	1,0E-06	2,0	0,64	40	0,49
8	0,1	0,090	K	**1090**		1120	29,3	3,2E+09	1,8E+08	0,65	1,1E-06	2,0	0,69	50	0,49
8	0,1	0,090	K	**1100**		1070	30,1	2,7E+09	2,8E+08	0,61	1,2E-06	2,0	0,82	50	0,50
8	0,1	0,090	K	**1110**		1010	26,9	2,7E+09	1,0E+09	0,62	1,2E-06	2,0	0,78	60	0,48
8	0,1	0,090	K	**1120**	40	990	29,4	8,7E+08	4,7E+08	0,65	1,1E-06	2,0	0,87	60	0,48

Table 2

Patentkrav

1. Et piezokeramisk materiale med reduceret blyindhold baseret på kaliumnatriumniobat (PSN) af basissammensætningen

$(K_xNa_yLi_{1-x-y})a\ (Mn_uTa_vSb_wNb_{1-u-v-w})O_3$, med

$0<x<1\ y$; $0<y<1$; $0<u<0{,}01$; $0<v<0{,}3$; $0\leq w<0{,}2$ og

$0{,}95<a<1{,}05$; $x+y\leq 1$;

kendetegnet ved

tilsætningen af en blanding af Pb, Nb og eventuelt Ag ifølge k vægt% Pb + I vægt% Nb + m vægt% Ag med

$0<k<0{,}5$; $0<I<1$; $0\leq m<1$.

2. Piezokeramisk materiale ifølge krav 1, **kendetegnet ved, at** $0{,}001<k\leq 0{,}2$.

3. Piezokeramisk materiale ifølge et af kravene 1 eller 2, **kendetegnet ved, at** $0<I\leq 0{,}179$.

4. Piezokeramisk materiale ifølge mindst et af de foregående krav, **kendetegnet ved, at** $0{,}001<k\leq 0{,}2$ og $0<I\leq 0{,}179$.

5. Piezokeramisk materiale ifølge mindst et af de foregående krav, **kendetegnet ved, at** $0{,}001<k\leq 0{,}1$.

6. Piezokeramisk materiale ifølge mindst et af de foregående krav, **kendetegnet ved, at** $0{,}022<I\leq 0{,}09$.

7. Piezokeramisk materiale ifølge mindst et af de foregående krav, **kendetegnet ved, at** $0{,}001<k\leq 0{,}1$ og $0{,}022<I\leq 0{,}09$.

8. Piezokeramisk materiale ifølge mindst et af de foregående krav, **kendetegnet ved, at** forholdet mellem k:I ligger i området fra 1:0,9 til 1:0,3.

9. Piezokeramisk materiale ifølge mindst et af de foregående krav, **kendetegnet ved** tilsætningen af en blanding af k vægt% Pb, I vægt% Nb og n vægt% Mn, hvor forholdet n:I ligger i området fra 0,05 til 0,15:0,30.

10. Piezokeramisk materiale ifølge krav 9, **kendetegnet ved, at** forholdet mellem k:n:I ligger ved 1:0,09:0,30.

11. Fremgangsmåde til fremstilling af et piezokeramisk materiale med reduceret blyindhold ifølge et af de foregående krav, **kendetegnet ved** de følgende trin:

- fremstilling af en råmaterialeblanding af basissammensætningen;
- fremstilling af en kalcin af basissammensætningen;
- finmalning af kalcinet;
- fremstilling af et granulat, især ved sprøjtegranulering eller fremstilling af en støbeslikker til flerlags- eller "co-firing"-processen;
- ydereligere bearbejdning på kendt måde, herunder sintring i normal atmosfære.

12. Piezokeramisk flerlagsaktuator på basis af et piezokeramisk materiale ifølge et af kravene 1 til 10.

13. Anvendelse af en blanding af Pb, Nb og eventuelt Ag i et piezokeramisk materiale baseret på kaliumnatriumniobat (PSN) af basissammensætningen

$(K_xNa_yLi_{1-x-y})a\ (Mn_uTa_vSb_wNb_{1-u-v-w})O_3$, med

$0<x<1$ y; $0<y<1$; $0<u<0{,}01$; $0<v<0{,}3$; $0\leq w<0{,}2$ og

$0{,}95<a<1{,}05$; $x+y\leq 1$;

til forøgelse af sintringsområdet for det piezokeramiske materiale, hvor tilsætningen af en blanding af Pb og Nb forekommer på en sådan måde at indholdet af tilsat Pb, Nb og Ag i vægtprocent relateret til hele det piezokeramiske materiale er som følger:

k vægt% Pb + I vægt% Nb + m vægt% Ag,

med

$0<k<0{,}5$; $0<I<1$; $0<m<1$, hvor området afgrænset af to temperaturspecifikationer skal forstås som sintringsområdet, indenfor hvilke de krævede egenskaber af det keramiske materiale er opnået under brændingen af materialet, hvilket defineres som følger:

tan δ:	$\leq 50\ 10^{-3}$
S3 (RT):	$> 0{,}6\ 10^{-3}$
Emax:	≤ 2 kV/mm

14. Anvendelse ifølge krav 13, **kendetegnet ved, at** $0{,}001<k\leq 0{,}2$ og $0<I\leq 0{,}0179$.

15. Anvendelse ifølge krav 13 eller 14, **kendetegnet ved, at** $0{,}001<k\leq 0{,}1$ og $0{,}022<I\leq 0{,}09$.

16. Anvendelse ifølge krav 14 eller 15, **kendetegnet ved, at** forholdet mellem k:I ligger i området fra 1:0,9 til 1:0,3.

17. Anvendelse ifølge krav 15 eller 16, **kendetegnet ved** tilsætningen af en blanding af k vægt% Pb, I vægt% Nb og n vægt% Mn, hvor forholdet n:I ligger i området 0,05 til 0,15:0,30.

18. Anvendelse ifølge krav 17, **kendetegnet ved, at** forholdet mellem k:n:I ligger ved 1:0,09:0,30.

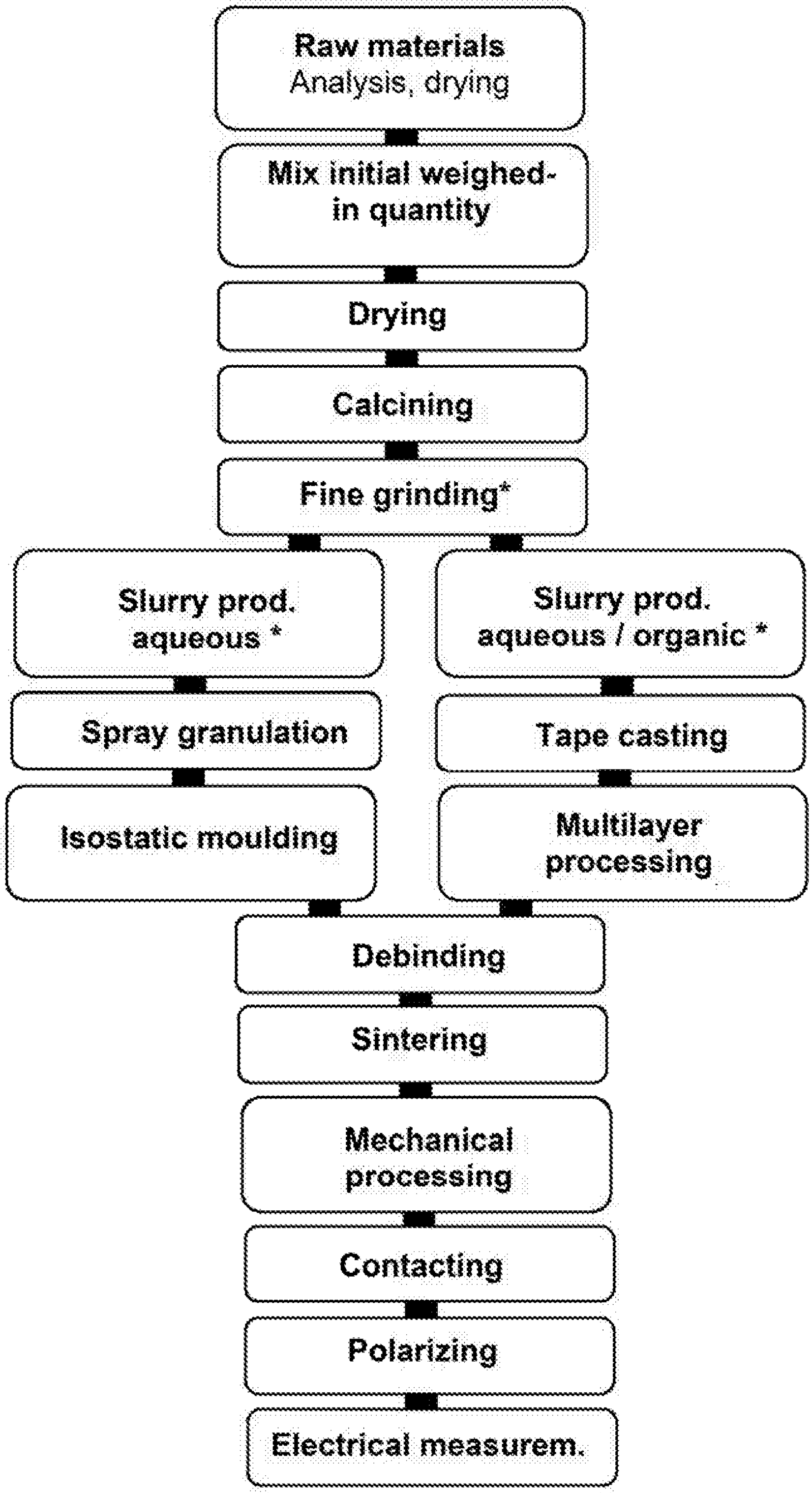
Raw materials
Analysis, drying
Mix initial weighed-in quantity
Drying
Calcining
Fine grinding*
Slurry prod. aqueous *
Slurry prod. aqueous / organic *
Spray granulation
Tape casting
Isostatic moulding
Multilayer processing
Debinding
Sintering
Mechanical processing
Contacting
Polarizing
Electrical measurem.

Fig. 1

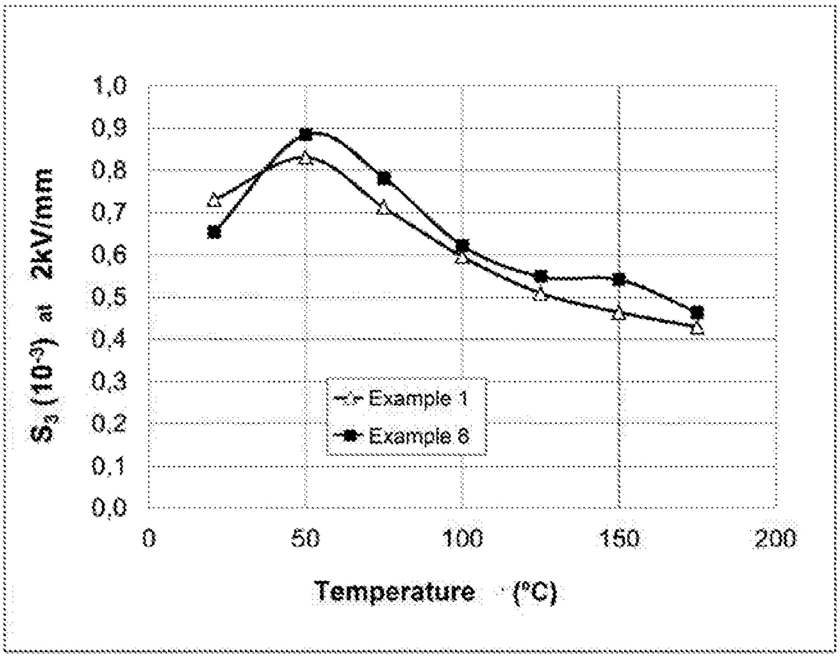
1,0
0,9
0,8
0,7
0,6
0,5
0,4
0,3
0,2
0,1
0,0
S3 (10-3) at 2kV/mm
0
50
100
150
200
Temperature (°C)
Example 1
Example 8

Fig. 2

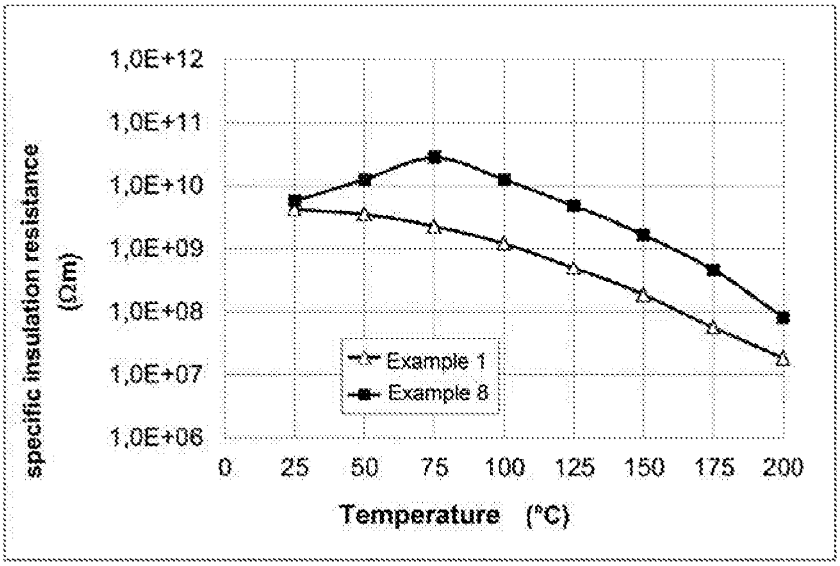
1,0E+12
1,0E+11
1,0E+10
1,0E+09
1,0E+08
1,0E+07
1,0E+06
specific insulation resistance (Ωm)
0
25
50
75
100
125
150
175
200
Temperature (°C)
Example 1
Example 8

Fig. 3

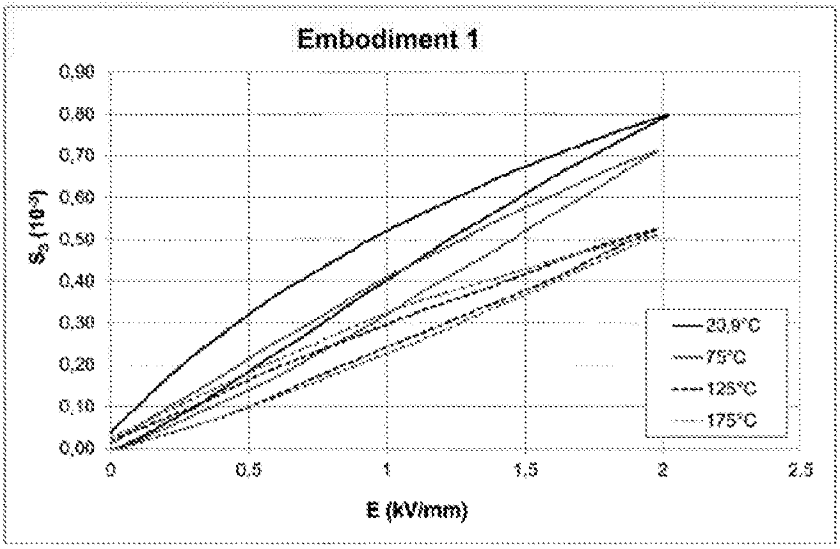
Embodiment 1
0,90
0,80
0,70
0,60
0,50
0,40
0,30
0,20
0,10
0,00
S_3 (10^{-3})
0
0,5
1
1,5
2
2,5
E (kV/mm)
20,9°C
75°C
125°C
175°C

Fig. 4a

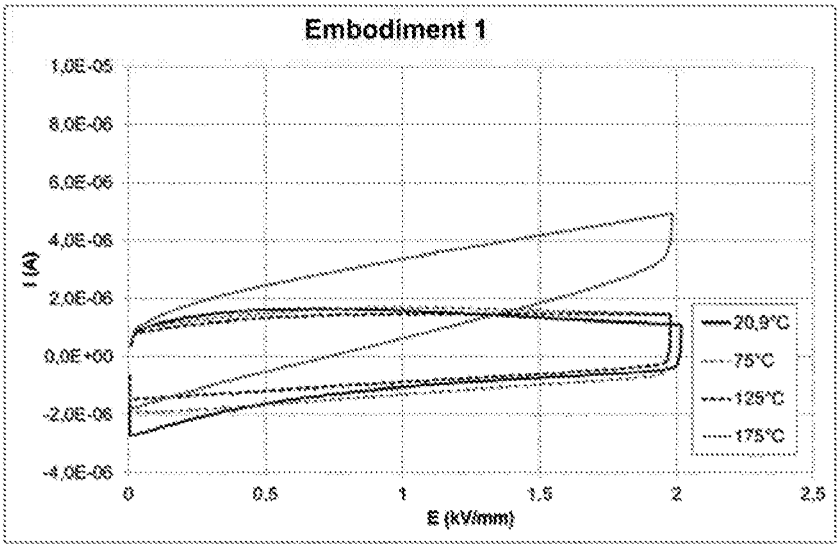
Embodiment 1
1,0E-05
8,0E-06
6,0E-06
4,0E-06
2,0E-06
0,0E+00
-2,0E-06
-4,0E-06
I (A)
0
0,5
1
1,5
2
2,5
E (kV/mm)
20,9°C
75°C
125°C
175°C

Fig. 4b

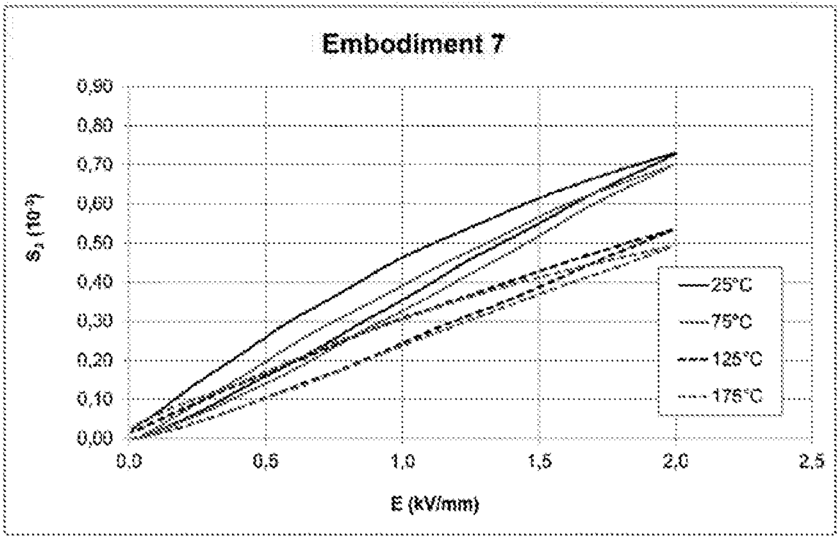
Embodiment 7
0,90
0,80
0,70
0,60
0,50
0,40
0,30
0,20
0,10
0,00
S_3 (10^{-3})
0,0
0,5
1,0
1,5
2,0
2,5
E (kV/mm)
25°C
75°C
125°C
175°C

Fig. 5a

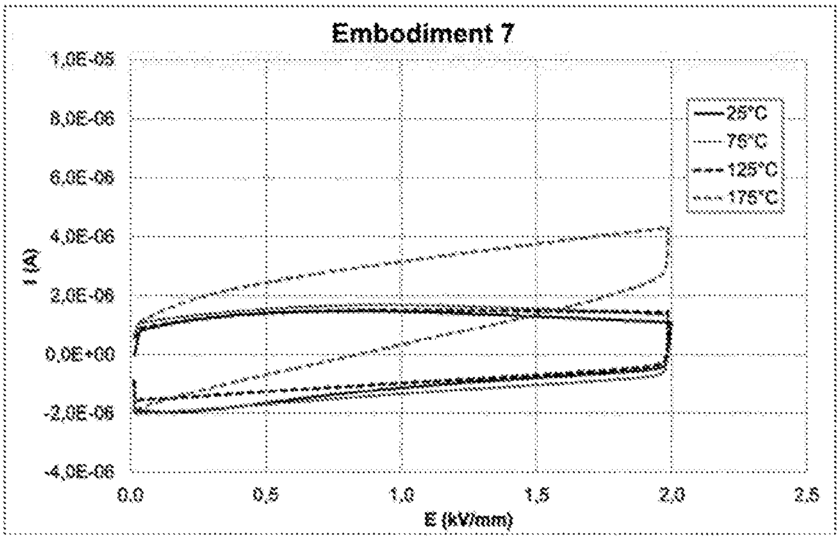
Embodiment 7
1,0E-05
8,0E-06
6,0E-06
4,0E-06
2,0E-06
0,0E+00
-2,0E-06
-4,0E-06
I (A)
0,0
0,5
1,0
1,5
2,0
2,5
E (kV/mm)
25°C
75°C
125°C
175°C

Fig. 5b

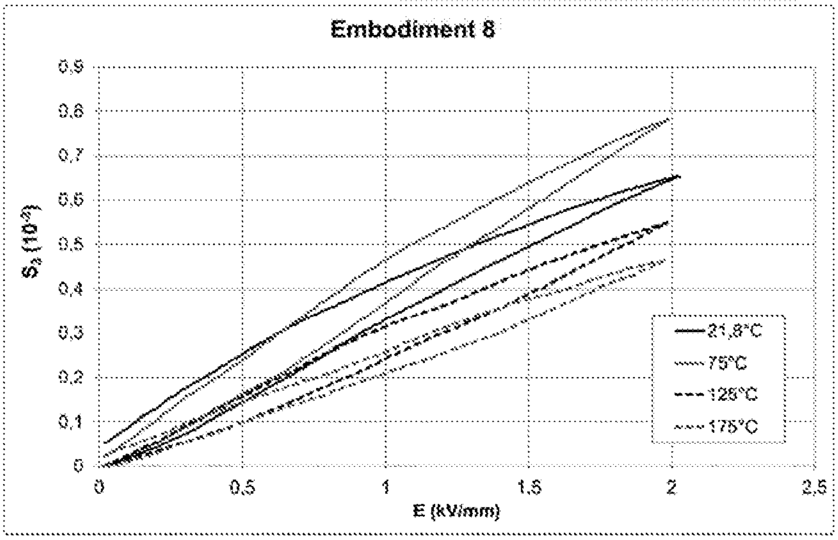
Embodiment 8
S_3 (10^{-3})
0,9
0,8
0,7
0,6
0,5
0,4
0,3
0,2
0,1
0
0
0,5
1
1,5
2
2,5
E (kV/mm)
21,8°C
75°C
125°C
175°C

Fig. 6a


Embodiment 8
I (A)
1,0E-05
8,0E-06
6,0E-06
4,0E-06
2,0E-06
0,0E+00
-2,0E-06
-4,0E-06
0
0,5
1
1,5
2
2,5
E (kV/mm)
21,8°C
75°C
125°C
175°C

Fig. 6b