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*THE EFFECTS OF SOME VARIATIONS IN
FABRICATION PROCEDURE ON THE
PROPERTIES OF LEAD ZIRCONATE-
TITANATE CERAMICS MADE FROM SPRAY-
DRIED, CO-PRECIPIATED POWDERS*

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The Effects of Some Variations in Fabrication Procedure on the Properties of Lead Zirconate-Titanate Ceramics Made From Spray-Dried Co-Precipitated Powders

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Introduction

It has been known for some time that lead zirconate and lead titanate form a continuous series of solid solutions which are ferroelectric for compositions containing more than about 8 mol % of the titanate, and that ceramics made from such compositions become piezoelectric on application of a sufficiently high d-c electric field⁽¹⁾. The electromechanical properties, which vary with composition, are strongest near a morphotropic boundary which occurs at 53.5 mol % lead zirconate^(2,3), and which separates a rhombohedral (zirconate-rich) from a tetragonal (titanate-rich) solid solution. In addition to the principal constituents, components present in smaller amounts may also cause variations in properties, as will changes in the procedures used to fabricate the ceramics.

The advantages in using co-precipitated powders as starting materials for the fabrication of piezoelectric ceramics of this type have been demonstrated in earlier investigations^(4,5), and a satisfactory method for producing co-precipitated lead-zirconium-titanium hydroxides suitable for this purpose has been described fully⁽⁶⁾.

Initial studies⁽⁴⁾ of the effect of sintering such co-precipitated mixtures were made on powders that had been vacuum-dried and that had to be milled in order to yield ceramics of satisfactorily high density. As sintering time, sintering temperature, and

Abstract

Lead zirconate-titanate piezoelectric ceramic disks were prepared from spray-dried, co-precipitated powders by cold-pressing and sintering. The effects of several processing variables on the electromechanical properties of the ceramics were determined. It was found that satisfactory samples could be fabricated from the spray-dried powders without milling, and that the forming pressure could be varied over a considerable range with little effect on the final properties. Disks sintered in oxygen showed only a slight improvement in properties over those sintered in air. In general, an increase in planar coupling factor could be achieved by increasing the sintering temperature or sintering time, but some decrease in dielectric constant was observed at the highest temperatures and longest times. Precipitates with a slight excess or deficiency of lead oxide tended toward stoichiometry with respect to lead oxide during sintering under appropriate conditions.

forming pressures were varied, the most important changes in electromechanical properties could be correlated with changes in density of the ceramics. Under the sintering conditions employed in those studies, and for the particular precipitates used, there were only minor changes in lead oxide content and in mean grain diameter of the ceramic. In later investigations⁽⁵⁾, it was found that, by careful control of precipitation conditions, by spray-drying the precipitates, and by milling the powders, sintered densities of over 99% of the theoretical crystal density could be achieved consistently.

The present study was undertaken to determine how variations in ceramic fabrication procedures might affect the electromechanical properties of ceramics made from the spray-dried powders by cold-pressing and sintering. The necessity of milling the powders, and of introducing oxygen during sintering were re-examined, and studies were made of the effects of forming pressure and the time and temperature of sintering. In addition, samples were prepared from a group of four precipitates in which the lead oxide content was deliberately varied above and below that

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required to form a stoichiometric lead zirconate-titanate solid solution. By studying the properties of these samples after firing under different conditions, the changes in lead oxide content during sintering and the effects of excess or deficiency of lead oxide on the properties of the ceramics could be assessed. Finally, ceramic samples coated with a number of different electrode materials were examined to determine whether the nature of the electrodes might have any effect on the measured properties of the ceramics.

Experimental procedures

1. Materials: As has been described previously⁽⁶⁾, the compositions used in this investigation were the hydroxides of lead, zirconium and titanium that were instantaneously co-precipitated from a blended metal nitrate solution of the desired stoichiometry. The precipitant used was ammonia gas. For certain batches of precipitate, carbon dioxide gas or, alternatively, ammonium carbonate solution was employed as an additional precipitant for the lead.

The precipitate was allowed to settle, the ammonium nitrate solution decanted and the precipitate washed by repeated batch decantations using demineralized water. The washed and settled slurries were spray-dried. In most investigations, the spray-dried powder was calcined at 700°C for 30 minutes, and not subsequently milled. Specific surface areas of the calcined powders were determined by nitrogen absorption from a helium-nitrogen mixture, using a Perkin-Elmer Sorptometer.

2. Fabrication of disks: After adding polyvinyl alcohol to act as a binder, the powder was pressed into disks in a 1-in. diameter mould, usually at 15,000 psi. The disks were left overnight in a desiccator containing CaSO₄ ("Drierite"). The samples were then placed in a zirconia rack along with disks of an equimolar mixture of PbO and ZrO₂, which were intended to provide a partial set in an electrically-heated furnace. The zirconia rack was placed in an alumina tube pressure of lead oxide in the furnace. The furnace was heated at 250 deg C/hr to the sintering temperature; a flow of oxygen was maintained up to 1000°C. After holding at the sintering temperature for the desired time, the disks were cooled overnight at the natural cooling rate of the furnace. Changes in dimensions and in weight during sintering were determined from measurements made immediately before and after the sintering step.

The sintered disks were ground and lapped to a uniform size, 1.84 cm diameter by 0.15 cm thick, and electrodes applied by sputtering with gold. Densities of the lapped disks were determined from their weights and dimensions.

Variations in the above procedure were made in individual experiments designed to evaluate the effect of various fabrication parameters, and will be noted where applicable.

3. Electromechanical measurements: The electroded disks were generally poled in groups at 100°C in a bath of transformer oil. In some investigations, the poling was carried out in 2 kV/cm steps to permit a study of dielectric breakdown but, in all cases, the samples were evaluated after poling at 36 kV/cm and at 40 kV/cm, measurements being made 24 hours after poling.

Evaluation of the electromechanical properties was limited to those parameters most readily measured on samples in the form of circular disks, i.e., the dielectric constant K_{33}^T , the dielectric loss or dissipation factor $\tan \delta$, and the planar coupling factor k_p . Dielectric measurements were made at 1 kc on a GR716C bridge, and the planar coupling factor was determined from resonance-antiresonance measurements in accordance with the appropriate IRE Standards⁽⁷⁾. Resistivity of unpoled samples was determined from two-terminal measurements with a megohmmeter, after two-minute electrification at 500 volts.

4. Chemical and structural examination: Chemical analysis was carried out by methods previously described by Barkley *et al*⁽⁸⁾. Average grain diameters were estimated by examination of etched polished sections⁽⁵⁾. X-ray powder diffraction patterns were taken with Cu K α radiation using a 114.7 mm Debye-Scherrer camera.

Experiments and Results

1. Effect of milling: The effect of milling co-precipitated lead zirconate-titanate powders in a Trost Jet Mill, model TXC, was examined using two precipitates, designated as D3-2 and D4-1. D3-2 had been prepared by precipitation with ammonia, and D4-1 had been prepared by precipitation with ammonia and ammonium carbonate⁽⁶⁾. Both uncalcined powder and powder calcined at 700°C were used. A portion of both the uncalcined and calcined powders of each precipitate was milled. Four disks were formed from a given precipitate using both milled (calcined and uncalcined) and unmilled (calcined and uncalcined) powders. The four disks were sintered together in the same cycle at 1240°C for 2 hours. Two such sintering cycles were carried out for each precipitate, to give a total of 16 disks. Analysis of variance on the properties of the disks indicated that the differences in properties between milled and unmilled materials were not significant at the 95% level of confidence. The results of measurements of sintered density and selected elec-

TABLE 1
Effect of Milling the Precipitates on Properties of the Fabricated Ceramics

Property	Precipitate D3-2		Precipitate D4-1	
	Not Milled	Milled	Not Milled	Milled
Sintered Density (g/cm ³)	7.93	7.93	7.90	7.90
Dielectric constant (before poling), K	1178	1184	1197	1196
Dielectric constant (after poling), K ₃₃ ^T	1177	1230	1259	1243
Planar coupling coefficient, k _p	0.57	0.56	0.60	0.60
Dielectric loss, tan δ	0.0074	0.0075	0.0065	0.0068
Specific surface area of precipitate calcined at 700°C (m ² /g)	10.2	10.5	9.8	11.6

- Notes: (1) Each entry (except for specific surface area) is the mean of determinations on 4 disks, 2 fabricated from calcined powder and 2 fabricated from uncalcined powder.
 (2) Disks were sintered at 1240°C for 2 hours.
 (3) Disks were poled at 36 kV/cm for 5 minutes.

trical properties are summarized in Table 1. The agreement between the electrical properties of disks made from milled and unmilled precipitates undoubtedly is a reflection of the similar densities attained during sintering. The high densities, about 99% of theoretical density (8.0 g/cm³), are probably achieved as a result of the high specific surface areas of the powders produced by co-precipitation followed by spray-drying. Only a relatively small increase in surface area is attained by breaking down into smaller particles the spheres of about 8 and 15 microns mean diameter (for D4-1 and D3-2 respectively) produced during the spray-drying. In agreement with previously reported results, calcination of the powder made no change in the properties of the fabricated ceramics⁽⁵⁾.

2. Effect of forming pressure: A series of disks was made using 6 different forming pressures from 5,000 to 50,000 psi. In the course of three sintering cycles, three disks made at each pressure were sintered at 1240°C for 2 hours. The results of examination of these disks are given in Table 2.

The diametral shrinkage during sintering decreased as the forming pressure was increased as would be expected. Little variation in sintered density was noted, although

there may have been a very slight trend to lower sintered densities for disks made at the lower forming pressures. No systematic variation of dielectric constant, planar coupling coefficient or dielectric loss with forming pressure was observed. The slopes of the regression lines of the values of each of these properties on forming pressure were not significantly different from zero at the 95% level of confidence. On the basis of the examination of polished sections of three disks, it was concluded that no systematic changes in the grain size of the sintered ceramics were associated with the changes in forming pressure.

3. Precipitates with various PbO/ZrO₂ + TiO₂ molar ratios: The compositions of the group of precipitates with various PbO/ZrO₂ + TiO₂ molar ratios are shown in Table 3. Precipitate P1 had an excess of PbO over that required for a stoichiometric lead zirconate-lead titanate solid solution, while precipitates P2 and P3 are closer to the stoichiometric ratio (unity) with only slight excesses of PbO. The precipitate P4 was deficient in PbO. The ZrO₂/ZrO₂ + TiO₂ ratios vary by less than 1% among the four precipitates. Ammonia and carbon dioxide had been used to precipitate P3, while ammonia alone had been used to precipitate

TABLE 2
Effect of Forming Pressure on Properties of Fabricated Ceramics

Forming Pressure (psi)	Diametral Shrinkage during Sintering (%)	Sintered Density (g/cm ³)	K ₃₃ ^T	k _p	tan δ	Mean Grain Diameter (microns)
5 × 10 ³	26.5	7.92	1025	0.58	0.0149	2.2
10 × 10 ³	24.3	7.94	1098	0.58	0.0147	—
20 × 10 ³	21.8	7.96	1089	0.58	0.0142	1.9
30 × 10 ³	20.8	7.94	1143	0.56	0.0174	—
40 × 10 ³	19.0	7.96	1079	0.58	0.0141	—
50 × 10 ³	18.2	7.96	1012	0.58	0.0119	2.1

- Notes: (1) Precipitate D3-1, calcined at 700°C; disks sintered at 1240°C for 2 hours and poled at 36 kV/cm.
 (2) Each entry is mean of determinations on 3 disks, except for mean grain diameters which were determined on one disk only.

TABLE 3

Comparison of Precipitates with Various $\frac{\text{PbO}}{\text{ZrO}_2 + \text{TiO}_2}$ Molar Ratios

Precipitate Number	P1	P2	P3	P4
Analysis of precipitate:				
$\frac{\text{ZrO}_2}{\text{ZrO}_2 + \text{TiO}_2}$ mole ratio	0.537	0.537	0.536	0.540
$\frac{\text{PbO}}{\text{ZrO}_2 + \text{TiO}_2}$ mole ratio	1.028	1.007	1.009	0.977
% wt change during sintering	-2.0	-0.8	-1.2	+0.9
Analysis of sintered disks:				
$\frac{\text{ZrO}_2}{\text{ZrO}_2 + \text{TiO}_2}$ mole ratio	0.540	0.538	0.539	0.537
$\frac{\text{PbO}}{\text{ZrO}_2 + \text{TiO}_2}$ mole ratio	1.009	1.006	1.005	1.005
Properties of sintered disks:				
Density (g/cm ³)	7.97	7.96	7.96	7.96
Dielectric constant (before poling), K_T	855	920	962	950
Dielectric constant (after poling), K_{33}^T	639	640	628	696
Planar coupling coefficient, K_R	0.56	0.56	0.57	0.54

Note: Disks were sintered at 1240°C for 2 hours and poled at 40 kV/cm for 10 minutes.

the other three samples. X-ray diffraction examination of disks made from these powders indicated the presence of the rhombohedral phase.

It was observed that the calcined precipitates that had excess PbO lost weight during sintering while the precipitate with a deficiency of PbO gained weight. These weight changes are probably due to transfer of PbO between the disks and the furnace atmosphere, which was provided with a partial pressure of lead oxide by the lead zirconate disks placed in the furnace. Analysis of the sintered disks confirmed that the compositions approach stoichiometry with respect to lead oxide content during sintering. Some weight loss, independent of changes in lead oxide content, is to be expected as a result of the decomposition of the binder and the loss of any residual volatiles in the powder.

The results presented in Table 3 indicate that all precipitates sintered to about the

same density and showed similar dielectric constants and planar coupling coefficients. It would appear, under the sintering conditions used, that deviations from stoichiometry with respect to lead oxide tend to decrease during the sintering cycle. Thus differences in properties which might otherwise be observed as a result of differences in lead oxide content in the ceramic are lessened. However, as will be seen subsequently, the choice of different sintering conditions could lead to different lead oxide contents in the sintered disks.

4. Effects of sintering time and sintering temperature: A group of disks was prepared from a precipitate (D2-1) that had a ratio $\text{PbO}/\text{ZrO}_2 + \text{TiO}_2 = 0.972$, i.e., a precipitate deficient in lead oxide. The disks, made from powder calcined at 700°C, were sintered for four different sintering times at three different temperatures, 1170°C, 1220°C, and 1270°C. The change in weight

TABLE 4
Effect of Sintering Time and Sintering Temperature on
 PbO/TiO_2 Molar Ratio

Sintering Temperature	Molar Ratio	
	Sintering Time 20 min	Sintering Time 5 hr
1270°C	2.12 ₀	2.13 ₅
1170°C	2.09 ₂	2.12 ₀

Note: Disks were made from precipitate D2-1 which had an initial ratio $\text{PbO}/\text{TiO}_2 = 2.06_4$.

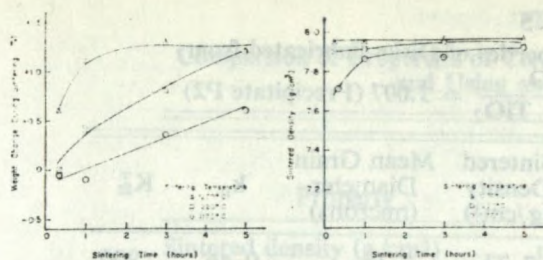


Figure 1: Weight change during sintering and sintered density as functions of sintering time and sintering temperature. Precipitate D2-1.

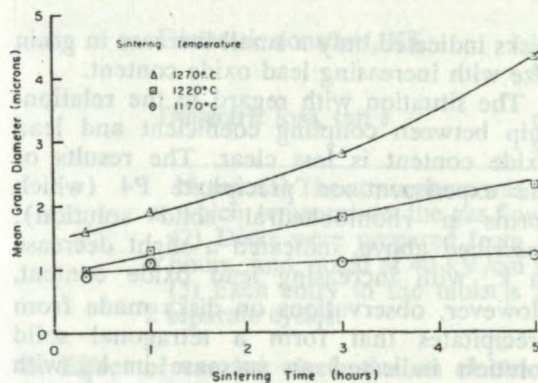


Figure 2: Effect of sintering time and sintering temperature on the mean grain diameters of lead zirconate-titanate ceramics. Precipitate D2-1.

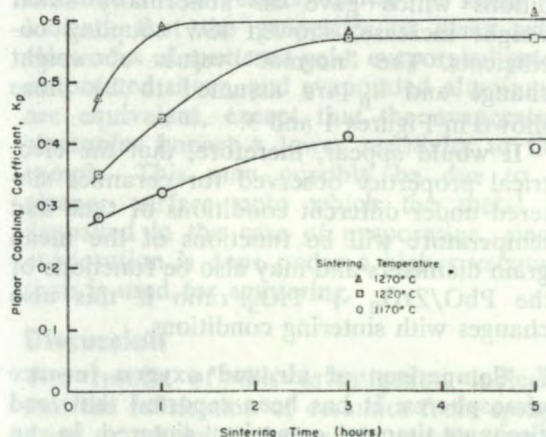


Figure 3: Effect of sintering time and sintering temperature on the planar coupling coefficient. Precipitate D2-1. Disks poled at 36kV/cm.

during sintering is plotted in Figure 1 as a function of sintering time and of sintering temperature. It would appear that the material takes up lead oxide from the furnace atmosphere, and that the rate of absorption increases as the temperature is raised, as would be expected. The disks appeared to reach an equilibrium with the furnace atmosphere at the highest temperature after about 2 hours. The increase in lead oxide content of the disks with increasing sintering time and increasing sintering temperature is confirmed by the analysis of selected disks, presented in Table 4 as PbO/TiO₂ molar ratios. The sintered densities of the disks are also shown in Figure 1. Except for the disks sintered at 1170°C for 20 minutes, all the density means were over

98% of theoretical and, hence, differences in sintered densities probably contributed little to the observed differences in electrical properties. The mean grain diameters, as determined on one disk sintered under each condition, are plotted in Figure 2. Higher rates of grain growth at higher temperatures are observed, as would be expected.

The planar coupling coefficient is shown as a function of sintering time and of temperature in Figure 3. In general, the coupling coefficient increases with increasing sintering temperature and increases with longer sintering times until a limit is reached. The dielectric constant, measured on poled disks, is plotted in Figure 4. The dielectric constant in general decreases with increasing sintering temperature, and, for the higher sintering temperatures, also decreases for disks sintered for longer times.

It may be observed that the data for both coupling coefficient and for dielectric constant can be correlated empirically with either the mean grain diameter or with the weight change during sintering (which is assumed to be a reflection of the lead oxide content of the disks) and, hence, it is not possible, on the basis of the results considered so far, to conclude whether the electrical properties are functions of grain size, of lead oxide content, or of both. It should be noted that the electrical properties could also depend on other physical or chemical properties of the disks that might vary with sintering time or temperature.

5. Effect of grain size: The results obtained by sintering a series of disks prepared from a precipitate (P2) with a slight excess of lead oxide ($\text{PbO/ZrO}_2 + \text{TiO}_2 = 1.007$) under three different conditions of time and temperature are shown in Table 5. The weight changes during sintering are about the same for all the sintering conditions and, hence, it may be concluded that the lead oxide contents of the disks are similar. The mean grain diameters, however, do change with the sintering conditions. The coupling coefficient is lowest for the material with the smallest grain size. It is estimated that the difference in density between the disks sintered under the first and second sets of conditions could account for only about one third of the change in coupling coefficient (4). A decrease in coupling factor for ceramics with mean grain diameters less than about 1.5 to 2 microns is consistent with the results of the previous section where, however, the decrease was more pronounced. A decrease in dielectric constant with increasing grain size is also indicated, in agreement with the results of the previous section.

6. Effect of changes in lead oxide content: A series of disks with various lead oxide contents was prepared from a lead-deficient precipitate (P4). These disks were sintered

TABLE 5
Effect of Sintering Conditions on Properties of Disks Fabricated from
Precipitate with Molar Ratio $\frac{\text{PbO}}{\text{ZrO}_2 + \text{TiO}_2} = 1.007$ (Precipitate P2)

Sintering Conditions	Weight Change During Sintering (%)	Sintered Density (g/cm ³)	Mean Grain Diameter (microns)	k _p	K ₃₃ ^T
1170°C for 20 minutes	-0.7	7.72	0.9	0.46	990
1240°C for 2 hours	-0.8	7.96	2.1	0.56	640
1270°C for 3 hours	-0.8	7.95	3.1	0.56	560

Note: Disks were poled at 40 kV/cm.

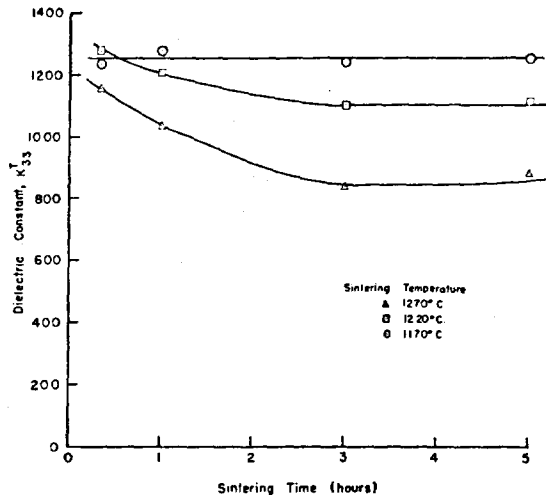


Figure 4: Effect of sintering time and sintering temperature on the dielectric constant, K_{33}^T . Precipitate D2-1.

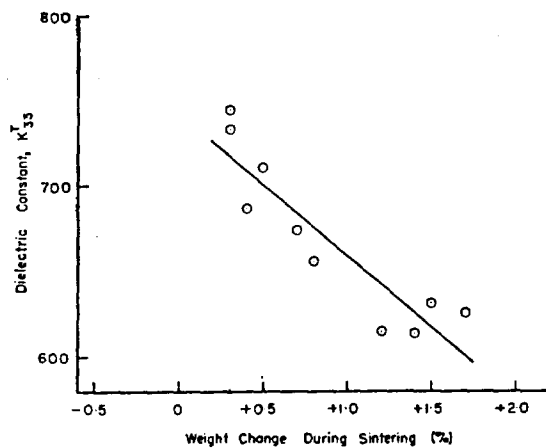


Figure 5: Dielectric constant as a function of weight change during sintering. Precipitate P4, sintered at 1260°C for two hours.

at 1260°C for 2 hours in different cycles in which the number and positions of the lead zirconate disks were changed. The dielectric constants of this series of disks are plotted in Figure 5 as a function of weight change on sintering. A decrease in dielectric constant with increasing lead oxide content is indicated. This is in qualitative agreement with the results of the study of varying sintering times and temperatures. Examination of polished sections of three of these

disks indicated only a small increase in grain size with increasing lead oxide content.

The situation with regard to the relationship between coupling coefficient and lead oxide content is less clear. The results of the experiment on precipitate P4 (which forms a rhombohedral solid solution), described above, indicated a slight decrease in k_p with increasing lead oxide content. However, observations on disks made from precipitates that form a tetragonal solid solution indicated an increase in k_p with increasing lead oxide content. For example, disks made from precipitate D2-1 and sintered at 1220°C for 5 hours under conditions which gave an abnormally small weight increase, showed low coupling coefficients. The "normal" values of weight change and k_p are assumed to be those shown in Figures 1 and 3.

It would appear, therefore, that the electrical properties observed for ceramics sintered under different conditions of time and temperature will be functions of the mean grain diameters and may also be functions of the $\text{PbO}/\text{ZrO}_2 + \text{TiO}_2$ ratio if this also changes with sintering conditions.

7. Comparison of air and oxygen furnace atmospheres: It has been reported that lead zirconate-titanate ceramics, sintered in an oxygen atmosphere, have better properties than those sintered in an air atmosphere⁽⁹⁾. A comparison between the oxygen atmosphere normally used in the present study and an air atmosphere was undertaken. In the present study, the atmosphere flow was discontinued at 1000°C to minimize any flushing of lead oxide vapour out of the furnace. An alumina plug separated the samples from the tube used to introduce the atmosphere. The results of this study are shown in Table 6. Two firing cycles, with three disks each, were carried out using each of the two atmospheres. The only difference found was a slightly lower density for the disks fired using the air atmosphere. The very slight variation in coupling coefficient, which is not significant, can be attributed to the variation in density. The lower sintered densities reached by the ceramics fired in the air atmosphere may possibly be attributed to nitrogen entrapped in closed pores⁽¹⁰⁾.

TABLE 6

Comparison of Properties of Ceramics Sintered Using an Air Atmosphere and Using an Oxygen Atmosphere

Property		Atmosphere	
		Air	Oxygen
Sintered density (g/cm ³)	mean	7.82	7.96
	std. dev.	±0.01	±0.01
Planar coupling coefficient, k_p	mean	0.58	0.59
	std. dev.	±0.01	±0.01
Dielectric constant, K_T^*	mean	1087	1080
	std. dev.	±54	±65
Dielectric loss, $\tan \delta$	mean	0.0113	0.0113
	std. dev.	±0.0017	±0.0016

Notes: (1) The atmosphere was introduced into the furnace up to 1000°C, at which temperature the gas flow was discontinued.

(2) Disks were prepared from precipitate D3-1, sintered at 1240°C for 2 hours, and poled at 40 kV/cm for 5 minutes.

(3) Each entry in the table is based on 6 disks, 3 sintered in each of 2 separate cycles.

8. Effect of varying electrodes on electrical properties: The effects of four different types of electrodes on the observed electrical properties of lead zirconate-titanate disks were examined. The results, shown in Table 7, indicate that the properties of disks with electrodes of sputtered gold, evaporated gold, evaporated silver, and evaporated aluminum are equivalent, except that the evaporated electrodes impart a lower resistivity to the sample. This may possibly be due to a cleaner surface onto which the metal is deposited in the case of evaporation, since evaporation is done under a higher vacuum than is used for sputtering.

Discussion

The results of this investigation indicate that the fabrication of ceramics from spray-dried co-precipitated powders can be simplified by the omission of the milling step. A further simplification could be achieved by omission of the calcination also. However, disks made from certain uncalcined precipitates tend to crack during sintering and the shrinkage during sintering is quite high. In the present investigation, calcination of the powder permitted the use of weight changes

to monitor changes in the PbO content of the disks.

The principal effect found on changing from an oxygen atmosphere to an air atmosphere during sintering was a decrease in sintered density. The use of different starting material or different firing conditions might have increased the density difference between oxygen-fired and air-fired disks, and correspondingly the differences in electrical properties might also have been larger. Such larger differences in density and in coupling factor were observed by Murray and Dungan⁽⁹⁾. It would appear that an oxygen atmosphere is to be preferred to an air atmosphere.

The lead oxide content of the sintered disks appears to be sensitive to the initial PbO content of the precipitate, to the sintering conditions (time and temperature), and to the provision made for a PbO partial pressure in the furnace. A suitable choice of sintering conditions, together with the use of PbZrO₃ to supply a PbO atmosphere, will tend to eliminate small deviations from stoichiometry with respect to PbO content. The rate of diffusion of PbO into disks deficient in PbO, however, is finite, and the

TABLE 7

Effect of Type of Electrode on Electromechanical Properties

Electrode	k_p	K_T^*	$\tan \delta$	Resistivity (ohm-meter)	Breakdown Field (kV/cm)
Sputtered gold	0.56	1239	0.0123	16.3×10^9	40
Evaporated gold	0.56	1264	0.0108	5.6×10^9	41
Evaporated silver	0.56	1253	0.0109	5.5×10^9	42
Evaporated aluminum	0.55	1295	0.0118	6.0×10^9	39

Note: Disks made from precipitate D3-1 were sintered at 1240°C for 2 hours and poled at 40 kV/cm.

approach to stoichiometry of such disks will depend on the sintering time and temperature. The control of stoichiometry with respect to PbO content is important, since it affects the electrical properties of the disks.

Changes in grain size of the ceramics also appear to affect the electrical properties. Ceramics with mean grain diameters much below 2μ appear to have lower coupling coefficients; on the other hand, the dielectric constants of the ceramics appear to increase with decreasing grain size. Haertling⁽¹¹⁾ has reported an increase in coercive field and a decrease in remanent polarization as the grain size becomes small. A brief report of work by Gesemann⁽¹²⁾ also indicated that the coupling coefficient increases up to a certain grain size and that the increase is related to a higher remanent polarization.

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ERRATUM

On page 62, Section 2, "Fabrication of disks:", line 10, beginning "set in ..." has been inadvertently interchanged with line 12, beginning "pressure of ...".

APPENDIX

ELECTRONIC CERAMICS ECRDC RESEARCH PROJECT C 73

Identification of Mines Branch Personnel

Advisory Committee

Mr. Ian F. Wright, MPD*, Chairman
Mr. W. A. Gow, EMD
Dr. N. F. H. Bright, MSD
Mr. J. G. Brady, MPD
Mr. V. A. McCourt, MPD

Operational

Function

Mr. V. M. McNamara, EMD	Pilot plant ceramic powder preparation
Mr. J. C. Ingles, EMD	Control analyses
Dr. A. H. Webster, MSD	Sintering and structural studies
Mr. V. A. McCourt, MPD	Lapidary and electroding
Mr. Ian F. Wright, MPD	Ceramic engineering
Mr. T. B. Weston, MPD	Electronic test methods and component evaluation
Mr. W. R. Inman, MSD	Wet chemical analytical methods and analyses
Dr. A. H. Gillieson, MSD	Spectrographic analyses
Dr. E. H. Nickel, MSD	Sample preparation for petrographic studies

*MPD - Mineral Processing Division
EMD - Extraction Metallurgy Division
MSD - Mineral Sciences Division

Ian F. Wright
Project Co-ordinator

John Convey
Director, Mines Branch