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Properties of Calcium-Barium Titanate Dielectrics

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Dielectrics having compositions in the system $3CaO:TiO_2$-$BaTiO_3$-TiO_2 were matured at 1,260° to 1,500° C. Data are given for the compositions, heat-treatments, absorption, shrinkage, and for K, the dielectric constant, and Q, the reciprocal of the power factor, at 25° C for frequencies of 50, 1,000 and 20,000 kilocycles per second and for 3,000 megacycles per second when K is not greater than 50. Values of K were also determined at 1 megacycle per second for various temperatures from −60° to +85° C. Lowest values of Q (and highest of K) were associated with specimens of high baria content. Linear thermal expansion (25° to 700° C) ranged from 0.65 to 0.87 percent. The specimens of some compositions were unstable and changed in K and Q values with time.

I. Introduction

This paper is the third of a series dealing with ceramic dielectrics composed of titanium dioxide and the oxides of the alkaline earth elements. A study of these titanate systems previously reported [1, 2] [1] revealed dielectrics of diverse properties that find application in the fields of electronic instrumentation, particularly where the space factor is important, as in hearing aids and other special circuits. These dielectrics are also valuable for the production of capacitors for use at temperatures above 150° C, where paper and electrolytic capacitors do not function satisfactorily.

A rather limited amount of information has been published by others [3, 4] on the electrical properties of the calcium-barium titanates. However, it is desirable to investigate these materials for a wide range in composition so that a more complete knowledge of their properties will be available. Because the temperature coefficient of the dielectric constant for calcium titanate was known to be negative, it was expected that many of the calcium-barium titanate dielectrics might have a negative coefficient. Also, the low electrical-loss character of calcium titanate indicated that a large portion of the field in this system would probably behave similarly.

[1] Figures in brackets indicate the literature references at the end of this paper.

II. Preparation of Dielectrics and Methods of Test

Dielectrics having the compositions shown in figure 1 were prepared from reagent quality carbonates of calcium and barium and the commercial grade of titania (grade TMO) used in the preparation of the other alkaline earth titanate dielectrics [1, 2]. A chemically pure grade of titania (99.9%) was used in the preparation of a few specimens for comparison purposes. The methods of preparing these dielectrics and of determining

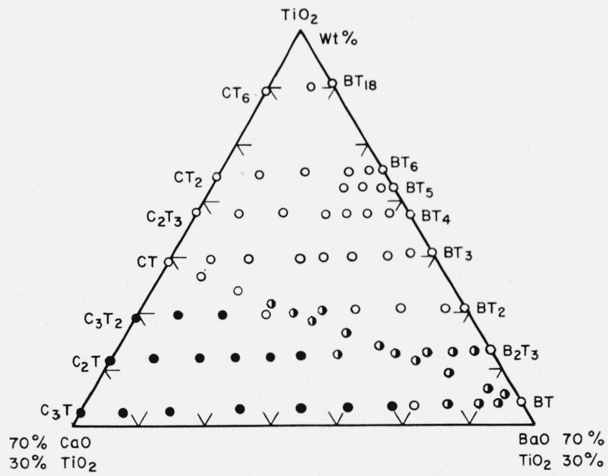

FIGURE 1. *Ternary diagram for system* CaO-BaO-TiO_2 *showing compositions studied.*

B=BaO; C=CaO; T=TiO_2; thus, B_2T_3=$2BaO:3TiO_2$. ●, Decrease in K and Q with time; ◑, decrease in K and increase in Q with time; ○, stable.

their properties have been previously described [1, 2].

III. Results and Discussion

In table 1, data are given for the composition, heat-treatment, absorption, shrinkage, dielectric constant *K*, and reciprocal of the power factor, *Q*, of the matured specimens. The data for a given composition are considered to be the most representative among those obtained from measurements of 3 to 11 test specimens.

TABLE 1. *Composition, heat treatment, absorption, shrinkage, dielectric constant K, and Q of bodies in the system* $3CaO:TiO_2$-$BaTiO_3$-TiO_2

Specimen designation	Proportion of end members of join, weight percent		Composition weight			Heat treatment				Absorption	Shrinkage	Dielectric constant *K* at 25° C and—				Reciprocal, *Q*, of power factor at 25° C and—			
						No. 1		No. 2											
			BaO	CaO	TiO_2	Temperature	Time	Temperature	Time			50 kc/s	1,000 kc/s	20 mc/s	3,000 mc/s	50 kc/s	1,000 kc/s	20 mc/s	3,000 mc/s
	$CaO:6TiO_2$-$BaO:18TiO_2$																		
			%	%	%	° C	hr	° C	hr	%	%								
CT6	100	-------	------	10.5	89.5	1,100	1	1,275	1	0.00	16.5	117	117	117	------	1,700	1,900	2,400	------
18BC6	33	67	6.5	3.5	90	1,100	1	1,275	1	.00	15.4	86	86	86	------	600	1,000	1,800	------
BT18	-------	100	9.6	------	90.4	1,100	1	1,275	1	.00	15.0	75	74	74	------	260	1,000	7,000	------
	$CaO:2TiO_2$-$BaO:6TiO_2$																		
CT2	100	-------	------	26.0	74.0	1,100	1	1,310	1	.00	18.0	142	141	141	------	1,900	1,200	1,800	------
6BC2	73	27	6.5	19.0	74.5	1,100	1	1,300	1	.01	15.6	107	107	107	------	700	500	1,000	------
6BC5	43	57	13.0	12.0	75.0	1,100	1	1,310	1	.00	17.1	84	83	83	------	3,000	1,400	2,700	------
6BC8	20	80	19.5	5.5	75.0	1,100	1	1,275	1	.00	16.4	60	60	60	------	3,000	4,000	10,000	------
6BC9	5	95	23.0	1.5	75.5	1,100	1	1,275	1	.00	15.9	49	49	49	48	2,000	10,000	10,000	960
BT6	-------	100	24.3	------	75.7	1,100	1	1,275	1	.00	13.7	46	45	44	39	85	400	2,200	490
	$2CaO:3TiO_2$-$BaO:4TiO_2$																		
C2T3	100	-------	------	31.9	68.1	1,100	1	1,310	1	.00	17.9	151	151	151	------	2,000	1,000	1,600	------
BC22	80	20	6.5	25.5	68.0	1,100	1	1,300	1	.06	15.8	115	114	114	------	700	300	700	------
BC24	60	40	13.0	19.1	67.9	1,100	1	1,295	1	.01	18.3	88	87	87	------	1,000	1,000	1,500	------
BC26	40	60	19.5	12.7	67.8	1,100	1	1,290	1	.00	16.8	68	68	68	------	2,000	1,600	4,000	------
BC27	30	70	22.7	9.6	67.7	1,100	1	1,290	1	.00	17.2	60	60	60	------	2,700	1,800	10,000	------
BC28	20	80	25.9	6.4	67.7	1,100	1	1,290	1	.00	17.2	51	51	50	47	2,600	4,000	10,000	940
BC29	10	90	29.2	3.2	67.6	1,100	1	1,290	1	.00	16.9	44	44	43	42	2,700	1,900	5,000	2,100
BT4	-------	100	32.4	------	67.6	1,100	1	1,330	1	.00	15.1	34	34	35	34	1,600	2,000	3,700	2,600
	$CaO:1.8TiO_2$-$BaO:5TiO_2$																		
5BC8	18	82	22.7	5.0	72.3	1,100	1	1,285	1	.00	17.0	56	56	56	------	560	600	1,000	------
5BC9	9	91	25.2	2.5	72.3	1,100	1	1,285	1	.00	16.0	49	49	49	------	700	550	850	------
5BC95	5	95	26.5	1.2	72.3	1,100	1	1,285	1	.00	15.1	45	45	45	------	750	770	1,000	------
BT5	-------	100	27.7	------	72.3	1,100	1	1,325	1	.04	12.0	39	37	37	------	1,500	2,300	1,300	------
	$CaO.TiO_2$-$BaO:3TiO_2$																		
CT	100	-------	------	41.2	58.8	1,100	1	1,400	1	0.01	16.7	143	143	143	------	2,000	3,500	800	------
BC2	83	17	6.5	34.4	59.1	1,000	1	1,320	5	[a]2.65	18.3	115	112	109	------	20	59	225	------
BC3	70	30	11.7	28.9	59.4	1,000	1	1,320	5	[a]1.62	19.4	112	110	107	------	25	90	570	------
BC5	50	50	19.5	20.6	59.9	1,000	1	1,275	2	0.00	19.0	94	94	94	------	1,300	1,200	1,100	------
BC6	40	60	23.4	16.5	60.1	1,100	1	1,290	1	.04	16.6	82	82	81	------	600	1,400	2,800	------
BC7	30	70	27.3	12.4	60.3	1,100	1	1,290	1	.00	17.0	72	72	71	------	1,600	2,400	4,000	------
BC8	17	83	32.4	7.0	60.6	1,100	1	1,290	1	.00	17.0	57	57	56	------	3,800	3,400	10,000	------
BC9	10	90	35.1	4.1	60.8	1,100	1	1,260	1	.00	17.7	52	52	51	50	2,400	3,600	10,000	1,240
BT3	-------	100	39.0	------	61.0	1,100	1	1,260	1	.03	17.4	44	44	43	42	650	720	800	460

TABLE 1. *Composition, heat treatment, absorption, shrinkage, dielectric constant K, and Q of bodies in the system* $3CaO:TiO_2$-$BaTiO_3$-TiO_2—Continued

Specimen designation	Proportion of end members of join, weight percent		Composition weight			Heat treatment				Absorption	Shrinkage	Dielectric constant K at 25° C and—				Reciprocal, Q, of power factor at 25° C and—			
			BaO	CaO	TiO_2	No. 1		No. 2				50 kc/s	1,000 kc/s	20 mc/s	3,000 mc/s	50 kc/s	1,000 kc/s	20 mc/s	3,000 mc/s
						Temperature	Time	Temperature	Time										
	$CaTiO_3$-$BaTiO_3$		%	%	%	° *C*	*hr*	° *C*	*hr*	%	%								
CT	100	-------	------	41.2	58.8	1,100	1	1,400	1	.01	16.7	143	143	143	------	2,000	3,500	800	------
CB1	90	10	6.6	37.1	56.3	1,100	3	1,430	1	.01	16.3	155	155	155	------	6,400	3,800	1,900	------
CB2	80	20	13.1	33.0	53.9	1,100	3	1,430	1	.01	15.7	185	185	185	------	2,300	2,100	1,200	------
CB3 [b]	70	30	19.7	28.9	51.4	1,100	3	1,430	1	.00	14.3	220	220	220	------	1,000	680	470	------
CB35 [b]	65	35	23.2	26.8	50.0	1,245	1	1,400	1	.05	13.1	240	240	240	------	1,000	700	520	------
CB4 [b]	60	40	26.3	24.7	49.0	1,100	3	1,430	1	.01	14.3	265	265	265	------	780	480	280	------
CB5 [b]	50	50	32.8	20.6	46.5	1,100	3	1,430	1	.03	13.8	315	315	315	------	600	390	190	------
CB6 [b]	40	60	39.4	16.5	44.1	1,100	3	1,430	1	.03	13.7	380	380	380	------	440	310	175	------
CB64 [b]	36	64	42.0	15.0	43.0	1,100	3	1,430	1	.00	13.4	400	400	400	------	460	270	130	------
CB7 [b]	30	70	46.0	12.4	41.6	1,100	3	1,430	1	.00	15.6	440	440	430	------	400	260	120	------
CB8 [b]	20	80	52.5	8.3	39.2	1,100	3	1,430	1	.00	14.6	540	540	530	------	570	325	175	------
CB9 [b]	10	90	59.1	4.1	36.8	1,100	3	1,430	1	.00	14.6	600	600	590	------	240	160	95	------
CB95 [b]	5	95	62.4	2.1	35.5	1,100	3	1,430	1	.02	14.3	840	840	830	------	130	120	80	------
BT	-------	100	65.7	------	34.3	1,245	1	1,385	2	.05	10.6	1,400	1,400	1,400	------	100	130	70	------
	$3CaO:2TiO_2$,-$BaO:2TiO_2$																		
C3T2	100	-------	------	51.3	48.7	1,245	1	1,500	1	.02	15.1	55	55	55	------	2,000	10,000	2,400	------
BC321	87	13	6.5	44.5	49.0	1,100	1	1,470	1	.00	14.1	67	67	67	------	2,000	3,000	2,000	------
BC323	74	26	13.0	37.5	49.5	1,245	1	1,500	1	.01	16.9	83	83	83	------	1,500	1,600	1,900	------
BC324	60	40	19.5	31.0	49.5	1,245	1	1,500	1	.01	17.0	150	150	150	------	1,600	1,600	1,700	------
BC325	53	47	23.2	26.8	50.0	1,100	1	1,420	1	.01	15.0	235	233	231	------	500	350	200	------
BC326	43	57	28.0	22.0	50.0	1,000	1	1,275	5	[a] .48	18.6	265	260	258	------	61	65	60	------
BC327	33	67	32.8	17.2	50.0	1,000	1	1,275	2	[a] .48	19.1	270	265	265	------	60	65	45	------
BC328	20	80	39.4	10.0	50.6	1,100	1	1,265	1	.04	17.3	215	210	209	------	80	65	43	------
BC329	6	94	46.0	3.0	51.0	1,100	1	1,265	1	.00	15.5	185	180	175	------	60	50	38	------
BT2	-------	100	49.0	------	51.0	1,100	1	1,290	1	.02	16.4	204	200	197	------	100	70	35	------
	$2CaO:TiO_2$-$2BaO:3TiO_2$																		
C2T	100	-------	------	58.4	41.6	1,100	1	1,500	[c] 1	.01	18.3	40	40	40	40	2,700	5,000	1,700	360
B2C21	89	11	6.2	52.0	41.8	1,100	1	1,500	1	.00	19.8	46	46	46	44	1,400	2,700	1,200	470
B2C22	76	24	13.2	44.6	42.1	1,100	1	1,500	1	.06	18.0	46	46	46	45	1,800	3,300	1,200	520
B2C23	68	32	18.1	39.5	42.3	1,100	1	1,450	1	.00	16.0	49	49	49	------	1,400	2,100	2,000	------
B2C24	58	42	23.7	33.7	42.6	1,100	1	1,500	1	.00	14.5	56	56	56	------	900	1,400	1,800	------
B2C25	50	50	28.1	29.2	42.7	1,100	1	1,430	1	.00	15.4	73	73	73	------	700	2,000	2,000	------
B2C26 [b]	40	60	33.7	23.3	43.0	1,100	1	1,500	1	.01	14.6	210	210	210	------	1,000	1,000	1,000	------
B2C28 [b]	17	83	46.6	9.9	43.5	1,100	1	1,280	3	[a] .23	14.6	480	480	470	------	67	55	35	------
B2C29 [b]	10	90	50.5	5.8	43.7	1,100	1	1,265	1	.00	14.6	520	515	500	------	50	33	25	------
B2C295 [b]	5	95	53.3	2.9	43.8	1,100	1	1,265	1	.00	15.5	580	570	550	------	40	27	20	------
B2T3	-------	100	56.1	------	43.9	1,250	1	1,300	1	.01	10.8	910	900	890	------	70	50	25	------
	$3CaO:TiO_2$-$BaTiO_3$																		
C3T	100	-------	------	67.8	32.2	1,100	1	1,500	1	.01	22.0	34	34	34	33	2,000	5,000	3,000	300
BC31	90	10	6.6	61.0	32.4	1,100	1	1,500	1	.00	24.0	40	40	40	38	1,200	2,600	2,400	580
BC32	80	20	13.1	54.2	32.6	1,100	1	1,500	1	.00	22.8	39	39	39	38	2,000	3,000	3,000	690
BC33	64	36	23.6	43.4	33.0	1,100	1	1,500	1	.00	18.8	37	37	37	37	1,400	4,000	6,000	430
BC35	50	50	32.9	33.9	33.2	1,100	1	1,500	1	.00	17.5	36	36	36	------	1,400	4,000	6,000	------
BC36	40	60	39.4	27.1	33.5	1,100	1	1,450	1	.00	16.7	37	37	37	36	2,000	4,000	9,000	350
BC37	29	71	46.6	19.7	33.7	1,100	1	1,470	1	.00	15.8	37	37	36	38	1,400	2,000	5,000	370
BC375	25	75	49.5	16.7	33.8	1,100	1	1,500	1	.00	15.9	60	60	60	------	1,300	5,000	5,000	------
BC38	16	84	55.0	11.0	34.0	1,245	1	1,430	1	.00	14.6	640	630	620	------	300	300	200	------
BC39 [b]	10	90	59.1	6.8	34.1	1,245	1	1,410	1	.00	13.6	1,640	1,630	1,620	------	170	190	110	------
BC395 [b]	5	95	62.4	3.4	34.2	1,100	1	1,410	1	.01	14.0	2,680	2,670	2,640	------	140	120	55	------
BT	-------	100	65.7	------	34.3	1,245	1	1,385	2	.05	10.6	1,400	1,400	1,400	------	100	130	70	------

[a] Not matured.

[b] K and Q values obtained after 6 months.

[c] Three heats at 1,500° C for 1 hr.

The relation between the maturing temperature and the composition of the specimens is shown in figure 2. No attempt was made to determine in all cases the range of temperatures within which mature specimens could be produced, but it was noted that, in general, this range was about 10° C. When the compositions were in the region of $CaO{:}2TiO_2$[2], containing a few percent of BaO, the maturing range was less than 10° C. This region may be near a ternary eutectic. In another area two mixtures, designated BC2 and BC3, and three other mixtures (BC326, BC327, and B2C28) did not yield mature specimens, despite many attempts with systematic variations in the duration and temperature of heat treatments. The lowest absorption obtained for these specimens was between 0.5 and 1.6 percent.

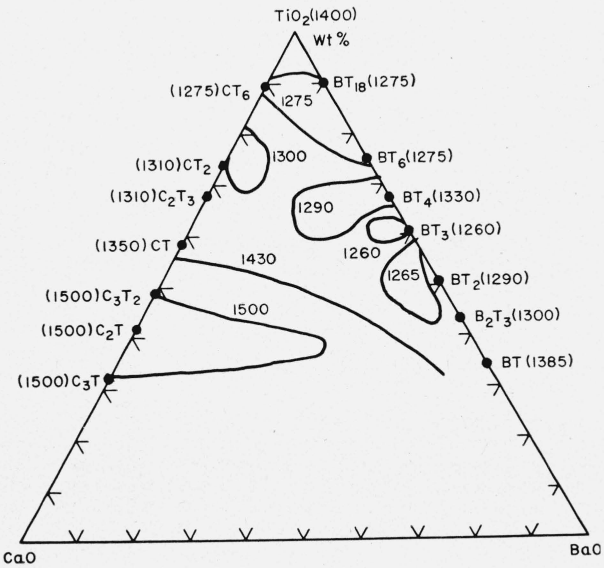

FIGURE 2. *Approximate maturing temperature (° C) after calcining treatment.*

B = BaO; C = CaO; T = TiO_2.

Small amounts of impurities have a pronounced effect on the maturing temperature of some preparations, particularly those representing a definite compound. If calcium titanate is prepared with titania containing 1.3 percent of impurities, the range in maturing temperature extends from 1,350° to 1,400° C. However, when less than a tenth of 1 percent of impurities is present, a maturing temperature of about 1,500° C is required.

[2] A colon indicates that the composition may or may not be a compound. A known compound is represented by a single dot separating the oxide formulae, or by a single formula, as $CaTiO_3$.

At 25° C the variations in K and Q, with composition, measured at 1 mc/s, are shown in figures 3 and 4, respectively. The ternary parts of these diagrams exhibit isodielectric-constant lines plotted from the data on K and Q given in table 1. Underneath and to the right side of the ternary diagram, the values of K (or Q) are plotted for the binary systems of CaO-TiO_2 and BaO-TiO_a. Systematically varying the compositions of the specimens affected the values of K and Q, as given in table 1.

In the CaO-TiO_2 system, the substitution of CaO for TiO_2, up to about 41 percent of CaO, raised the K value from near 100 for TiO_2 to about

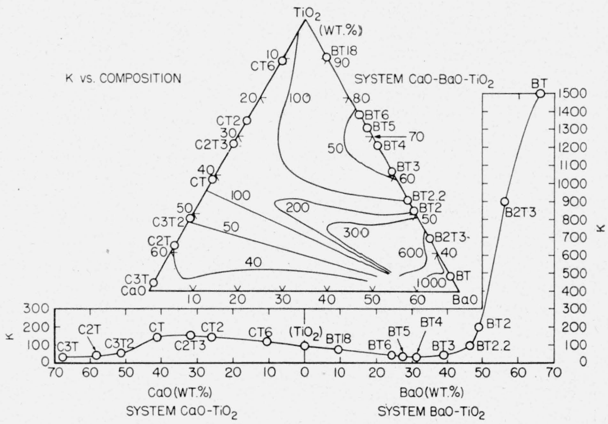

FIGURE 3. *Dielectric constant, at 25° C and 1 mc/s, with varying composition within the ternary system,* $3CaO{:}TiO_2$-$BaTiO_3$-TiO_2, *and the binary systems,* CaO-TiO_2 and BaO-TiO_2.

B = BaO; C = CaO; T = TiO_2.

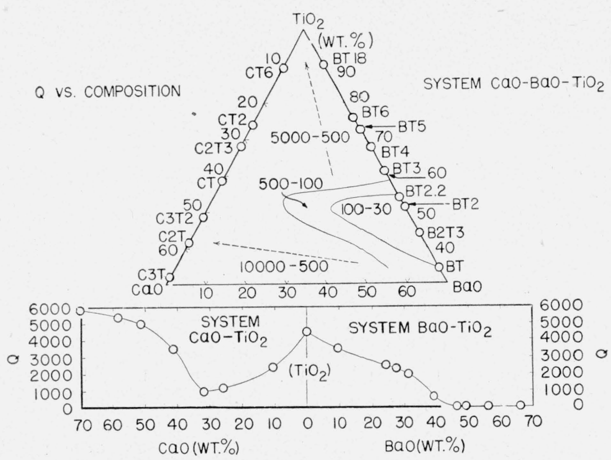

FIGURE 4. *Q values, at 25° C and 1 mc/s, with varying composition within the ternary system,* $3CaO{:}TiO_2$-$BaTiO_3$-TiO_2, *and the binary systems,* CaO-TiO_2 and BaO-TiO_2.

B = BaO; C = CaO; T = TiO_2.

140 for $CaTiO_3$ (fig. 3). Higher values, up to 168, have been reported by others [4]. The different values obtained were probably due to variations in the crystal development as influenced by impurities and heat-treatment. Q values (fig. 4) were progressively lowered when CaO replaced TiO_2 and became a minimum when the CaO content reached about 31 percent. Further additions of CaO increased the Q values.

Within the ternary system for dielectrics having percentages of TiO_2 greater than about 60, the replacement of BaO by CaO increased the values of K but did not greatly decrease those of Q, in contrast to the effect of replacing BaO by MgO [2]. However, for dielectrics having compositions on the join $CaTiO_3$-$BaTiO_3$, increasing the content of $CaTiO_3$ resulted in a continuous decrease in K, from about 1,400 for $BaTiO_3$ to near 140 for $CaTiO_3$, and in an increase in Q, from 130 for $BaTiO_3$ to 3,500 for $CaTiO_3$, measured at 25° C and 1 mc/s. For specimens having compositions along the join $3CaO{:}2TiO_2$-$BaO{:}2TiO_2$, the initial substitution of CaO for BaO resulted in a decrease in K from 200 to 180 and in Q from 70 to 50. Further increase in CaO content increased K to a maximum of 265 at 33 percent of $3CaO{:}2TiO_2$, followed by a decrease in K to 55 for 100 percent of $3CaO{:}2TiO_2$. Q values were below 100 for specimens containing less than about 50 percent of $3CaO{:}2TiO_2$ and above 200 at higher CaO content. Along the join $2CaO{:}TiO_2$-$2BaO{:}3TiO_2$, K for the dielectrics was continuously reduced, as CaO replaced BaO, from 900 for $2BaO{:}3TiO_2$ to 40 for $2CaO{:}TiO_2$. The Q value, although less than 100 when the percentage of $2CaO{:}TiO_2$ was 17 percent or less, was several hundred at higher CaO content. On the join $3CaO{:}TiO_2$-$BaTiO_3$, the replacement of $BaTiO_3$ by 5 percent of $3CaO{:}TiO_2$ increased K from 1,400 to 2,670, but additional replacement to 10 percent of $3CaO{:}TiO_2$ reduced K to 1,630. Further increase in the content of $3CaO{:}TiO_2$ to 25 percent resulted in a rapid decrease in K to a value of 60. From 29 percent to 100 percent, K remained near 40. The Q value was not over 300 from 0 to 16 percent of $3CaO{:}TiO_2$, but for higher percentages Q ranged from 2,000 to 5,000.

Certain specimens, indicated in figure 1, were found to decrease in K and increase in Q with time after the final heat treatment. Similar behavior was noted and described for some of the titanate dielectrics previously studied [2]. Data showing the extent of these changes after storage for 6 months under room conditions are given in table 2. Although the maximum decrease in K for any specimen was less than 25 percent, the maximum increase in Q was 225 percent. These changes appear only in the dielectrics containing less than about 50 percent of titania and more than about 25 percent of baria. In this region, the presence of the crystalline forms of $BaTiO_3$, with some solid solution, might be expected, and changes in this crystalline structure may be associated with the instability of the specimens. The data in table 1 were obtained after the K and Q values had been stabilized by aging these specimens for 6 months.

TABLE 2.—*Changes in K and Q of some specimens after 6 months of storage*

[Measured at 1 mc/s and 25° C]

Specimen designation	Dielectric constant, K			Quality factor, Q		
	After 1 day	After 6 months	Change	After 1 day	After 6 months	Change
			%			%
CB3	228	217	−4.8	305	680	128
CB35	249	238	−4.4	215	700	225
CB4	285	264	−7.4	200	480	140
CB5	347	315	−9.2	151	390	160
CB6	426	380	−10.8	105	310	195
CB64	464	401	−13.6	94	270	187
CB7	516	440	−14.7	90	264	193
CB8	657	542	−17.5	102	325	219
CB9	696	599	−13.9	66	159	141
CB95	860	838	−2.6	94	117	24
B2C26	213	209	−1.9	780	1,030	32
B2C28	495	477	−3.6	47	55	17
B2C29	542	514	−5.2	31	32.5	5
B2C295	590	571	−3.2	26	27	4
BC33	611	538	−12.0	290	294	1
BC39	1,630	1,397	−14.3	169	216	22
BC395	2,200	1,692	−23.1	65	117	80

All of the dielectrics containing less than 50 percent of titania and greater than about 30 percent of calcia (fig. 1) decreased in K and Q values after exposure to room conditions for over a year. These changes are probably due to the presence of free lime, which slowly hydrates as a result of exposure to moisture in the air. Specimens in the region of $3CaO{:}TiO_2$ disintegrate after storage for several weeks. The data given in table 1 for these dielectrics were obtained within a day or two after they were matured.

Changes in the dielectric constant due to variations in temperature are given in table 3. At 1 mc/s these data were obtained by measurements at temperatures given in the table. Equilibrium values of K were not attained for the specimens listed in table 2 for the reason that the temperature at each interval was held constant for only 15 min before measurements were made. For stable specimens, the average values of temperature coefficient of K per degree centigrade are considered to be within ±10 ppm, or 5 percent, whichever is greater. All but seven of these stable values are negative and lie within the range of 0 to −2,250 ppm per degree centigrade. Where no values are given, computations of the coefficient were not made because the coefficient either changed sign or showed large irregularities within this range of temperature. To illustrate the variation of K resulting from changes in temperature and composition, diagrams were constructed for temperatures of −60°, 0°, and 60° C (fig. 5). These diagrams exhibit isodielectric-constant lines plotted from the data in table 3. In contrast to specimens with compositions in the join $SrTiO_3$-$BaTiO_3$ [1], the dielectrics with compositions in the join $CaTiO_3$-$BaTiO_3$ do not have peak values of K within the temperature range of −60° to 85° C.

TABLE 3. *Dielectric constant, at 1 mc/s, from −60° to 85° C, and average temperature coefficient of dielectric constant per ° C*

Specimen designation	Values of *K* at—																Average temperature coefficient of *K* per ° C
	−60° C	−50° C	−40° C	−30° C	−20° C	−10° C	0° C	10° C	20° C	30° C	40° C	50° C	60° C	70° C	80° C	85° C	
																	ppm
CT6	131	129	127	125	123	121. 5	120	119	117. 5	116. 5	115	114	113	112	111	110. 5	−1, 200
18BC6	87. 8	86. 8	85. 9	85. 1	84. 4	83. 7	83. 0	82. 4	81. 7	81. 0	80. 4	79. 9	79. 4	78. 8	78. 3	78. 0	−820
BT18	80. 5	79. 7	78. 9	78. 3	77. 6	77. 0	76. 5	76. 0	75. 4	74. 8	74. 3	73. 8	73. 4	73. 0	72. 7	72. 5	−730
CT2	163. 5	160	157	154	151	148. 5	146	144	141. 5	139. 5	138	136	134. 5	133	131. 5	130. 5	−1, 590
6BC2	120	118	116	114	112	110. 5	109	108	106. 5	105. 5	104. 5	103. 5	102. 5	102	101. 5	101	−1, 220
6BC5	91. 7	90. 4	89. 2	88. 1	87. 1	86. 2	85. 6	85. 0	84. 4	83. 8	83. 2	82. 5	81. 8	81. 1	80. 4	80. 1	−940
6BC8	61. 5	60. 9	60. 4	59. 9	59. 6	59. 2	58. 9	58. 7	58. 6	58. 5	58. 4	58. 1	57. 8	57. 5	57. 1	57. 0	−530
6BC9	50. 3	50. 1	49. 9	49. 7	49. 5	49. 4	49. 2	49. 1	48. 9	48. 7	48. 6	48. 5	48. 4	48. 3	48. 2	48. 1	−310
BT6	46. 5	46. 3	46. 2	46. 0	45. 8	45. 6	45. 4	45. 3	45. 1	45. 0	44. 9	44. 8	44. 7	44. 6	44. 5	44. 5	−300
5BC8	58. 6	58. 2	57. 7	57. 3	56. 9	56. 6	56. 3	56. 0	55. 8	55. 5	55. 2	55. 0	54. 7	54. 5	54. 3	54. 2	−530
5BC9	50. 4	50. 1	49. 9	49. 7	49. 5	49. 4	49. 2	49. 1	49. 0	48. 9	48. 7	48. 5	48. 4	48. 3	48. 2	48. 15	−320
5BC95	46. 0	45. 8	45. 7	45. 5	45. 4	45. 3	45. 2	45. 1	45. 0	44. 9	44. 8	44. 7	44. 65	44. 6	44. 5	44. 45	−230
BT5	36. 7	36. 7	36. 7	36. 7	36. 7	36. 7	36. 7	36. 7	36. 7	36. 7	36. 7	36. 7	36. 7	36. 7	36. 7	36. 7	0
C2T3	169	165. 5	162	158. 5	156	152. 5	150	147. 5	145. 5	143. 5	141. 5	139. 5	138	136	134. 5	133. 5	−1, 650
BC22	114	112	110	108	106	104. 5	102. 8	101. 5	100. 2	99. 4	98. 1	97. 0	96. 0	95. 0	94. 0	93. 4	−1, 370
BC24	98. 4	96. 3	94. 5	93. 1	91. 7	90. 6	89. 5	88. 5	87. 5	86. 5	85. 6	84. 8	84. 1	83. 4	82. 7	82. 3	−1, 260
BC26	73. 0	71. 5	70. 5	69. 6	68. 9	68. 3	67. 8	67. 3	66. 9	66. 5	66. 1	65. 6	65. 1	64. 7	64. 2	64. 0	−920
BC27	61. 9	61. 4	60. 9	60. 3	59. 9	59. 5	59. 1	58. 6	58. 3	58. 1	57. 9	57. 7	57. 5	57. 4	57. 2	57. 1	−570
BC28	52. 4	52. 0	51. 6	51. 2	51. 0	50. 7	50. 4	50. 2	50. 0	49. 9	49. 7	49. 5	49. 4	49. 3	49. 2	49. 1	−460
BC29	41. 9	41. 8	41. 7	41. 6	41. 6	41. 5	41. 5	41. 5	41. 5	41. 5	41. 5	41. 5	41. 5	41. 5	41. 5	41. 5	−70
BT4	33. 0	33. 1	33. 2	33. 3	33. 4	33. 5	33. 6	33. 7	33. 7	33. 8	33. 9	33. 9	34. 0	34. 0	34. 0	34. 0	210
CT	169	165	161. 5	158	155	152	149	146. 5	144	142	139	137	135	133. 5	132	131	−1, 800
BC5	106. 4	104. 8	103. 0	101. 5	99. 8	98. 5	97. 2	96. 2	95. 2	94. 2	93. 2	92. 2	91. 3	90. 3	89. 3	88. 9	−1, 240
BC6	80. 2	79. 2	78. 0	77. 00	76. 0	75. 2	74. 4	73. 8	73. 3	72. 6	72. 0	71. 4	70. 8	70. 2	69. 7	69. 4	−980
BC7	73. 9	73. 0	72. 2	71. 4	70. 6	70. 0	69. 4	68. 9	68. 4	67. 9	67. 4	66. 9	66. 4	65. 9	65. 5	65. 3	−790
BC8	59. 9	59. 4	58. 8	58. 4	58. 0	57. 5	57. 2	56. 8	56. 5	56. 2	55. 9	55. 7	55. 4	55. 2	54. 9	54. 8	−620
BC9	53. 4	53. 1	52. 8	52. 6	52. 3	52. 1	51. 8	51. 6	51. 4	51. 2	51. 0	50. 8	50. 6	50. 4	50. 2	50. 1	−440
BT3	44. 6	44. 5	44. 5	44. 4	44. 3	44. 3	44. 2	44. 1	44. 1	44. 0	43. 9	43. 9	43. 8	43. 8	43. 7	43. 7	−160
CT	169	165	161. 5	158	155	152	149	146. 5	144	142	139	137	135	133. 5	132	131	−1, 800
CB1	186	181	176	171. 5	168	164. 5	161. 5	159	156	154	151. 5	149. 5	147	145	143	141. 5	−1, 940
CB2	237	229	223	216	211	206	201	197	193	189	185	181	178	176	174	173	−2, 250
CB3 [a]	254	248	244	238	234	230	227	225	224	225	226	228	231	236	242	250	--------
CB35 [a]	290	282	275	269	264	260	256	253	251	250	250	251	253	257	264	271	--------
CB4 [a]	295	290	285	282	279	276	274	273	275	279	284	291	302	315	331	346	--------
CB5 [a]	349	347	345	343	341	341	339	341	342	348	353	365	378	398	423	444	--------
CB6 [a]	409	407	407	406	404	405	406	410	413	427	440	460	483	517	570	604	--------
CB64 [a]	410	408	407	407	408	409	412	413	420	435	455	480	515	570	635	690	--------
CB7 [a]	415	420	420	425	430	435	440	445	450	480	510	550	600	660	770	835	4, 600
CB8 [a]	455	470	485	490	515	520	530	540	550	600	660	740	860	1, 020	1, 250	1, 600	7, 700

See footnote at end of table.

TABLE 3. *Dielectric constant, at 1 mc/s, from −60° to 85° C, and average temperature coefficient of dielectric constant per °C*—Continued

Specimen designation	Values of K at—																Average temperature coefficient of K per °C
	−60° C	−50° C	−40° C	−30° C	−20° C	−10° C	0° C	10° C	20° C	30° C	40° C	50° C	60° C	70° C	80° C	85° C	
																	ppm
CB9 [a]	670	655	640	640	635	640	640	640	640	660	680	720	765	825	905	960	--------
CB95 [a]	610	720	920	1,110	1,005	950	910	875	860	855	860	875	910	950	1,020	1,060	--------
BT	805	815	860	910	980	1,060	1,160	1,310	1,570	1,450	1,360	1,320	1,300	1,330	1,400	1,440	--------
C3T2	51.3	51.2	51.0	51.0	50.8	50.7	50.6	50.5	50.4	50.2	50.1	50.0	49.9	49.7	49.6	49.5	−260
BC321	67.7	67.3	66.9	66.5	66.1	65.7	65.3	65.0	64.6	64.2	63.9	63.6	63.3	63.0	62.7	62.5	−550
BC323	90.5	89.5	88.5	87.4	86.4	85.7	84.8	84.1	83.3	82.6	81.8	81.2	80.6	79.9	79.3	79.0	−950
BC324	174	169	165	161	157.5	154	152	150	149	146.5	144.5	142	140	138	136.5	135.5	−1,780
BC325	254	250	246	243	240	237	235	233	232	233	234	236	240	245	253	258	--------
BC327	260	260	261	261	262	263	264	265	266.5	268	270	272.5	275	277.5	280.5	282.5	590
BC328	200	201	202	203.5	205	206	208	210	212	214.5	217	220	223	227	232	235	1,150
BC329	151	153	155	157	160	162	165	167	171	174	177	181	185	191	197	204	2,200
BT2	163	168	173	177	182	187	192	196	200	202	204	207	210	214	219	221	2,100
C2T	40.23	40.2	40.15	40.1	40.0	39.95	39.9	39.85	39.8	39.7	39.65	39.6	39.5	39.45	39.4	39.37	−155
B2C21	46.3	46.2	46.15	46.1	45.95	45.9	45.8	45.7	45.6	45.45	45.4	45.3	45.25	45.15	45.1	45.05	−190
B2C22	45.7	45.6	45.5	45.4	45.35	45.3	45.2	45.1	45.05	44.95	44.85	44.8	44.7	44.6	44.5	44.45	−180
B2C23	47.4	47.55	47.7	47.8	47.95	48.1	48.2	48.3	48.4	48.25	48.1	48.0	47.9	47.8	47.7	47.68	--------
B2C24	59.2	58.8	58.3	57.9	57.5	57.15	56.8	56.6	56.3	56.0	55.75	55.5	55.25	55.05	54.8	54.6	−550
B2C25	79.7	78.8	77.9	77.0	76.2	75.5	74.8	74.2	73.6	72.9	72.4	71.9	71.4	70.9	70.4	70.2	−870
B2C26 [a]	236	233	230	227	224	221	217	214	210	207	204	200	196	192	187	185	−1,670
B2C28 [a]	464	470	480	487	495	503	512	518	525	535	547	560	573	590	608	617	2,020
B2C29 [a]	449	457	465	475	485	495	504	512	525	542	555	575	592	620	642	660	2,820
B2C295 [a]	474	485	497	510	523	535	550	560	580	593	610	633	655	685	715	742	3,270
B2T3	600	630	660	690	720	745	780	825	870	890	900	910	920	935	965	980	--------
C3T	34.35	34.3	34.25	34.2	34.15	34.1	34.1	34.05	34.0	33.95	33.9	33.9	33.85	33.8	33.75	33.72	−100
BC31	40.35	40.3	40.2	40.15	40.1	40.05	40.0	39.95	39.9	39.85	39.8	39.7	39.65	39.6	39.55	39.5	−145
BC32	39.02	38.95	38.9	38.85	38.8	38.75	38.7	38.65	38.62	38.6	38.5	38.45	38.4	38.35	38.3	38.28	−130
BC33	37.45	37.4	37.37	37.33	37.3	37.23	37.2	37.15	37.1	37.05	37.0	36.95	36.9	36.85	36.8	36.78	−130
BC35	35.92	35.85	35.83	35.8	35.8	35.75	35.75	35.7	35.7	35.65	35.6	35.55	35.5	35.45	35.4	35.38	−100
BC36	38.0	37.95	37.85	37.8	37.75	37.75	37.7	37.7	37.7	37.65	37.6	37.55	37.5	37.45	37.4	37.35	−50
BC37	38.55	38.3	38.0	37.8	37.5	37.3	37.15	37.05	36.9	36.75	36.6	36.4	36.3	36.15	36.05	35.95	−480
BC375	70.0	69.3	68.4	67.7	66.9	66.2	65.4	64.7	63.9	63.2	62.5	61.8	61.1	60.3	59.6	59.2	−1,130
BC38	500	520	540	555	575	590	600	600	600	600	580	555	525	495	460	440	--------
BC39 [a]	1,100	1,130	1,190	1,260	1,330	1,420	1,520	1,640	1,730	1,750	1,710	1,610	1,500	1,400	1,300	1,230	--------
BC395 [a]	1,400	1,460	1,520	1,570	1,640	1,710	1,800	1,860	1,880	2,000	2,460	2,920	3,020	2,860	2,590	2,500	--------
BT	805	815	860	910	980	1,060	1,160	1,310	1,570	1,450	1,360	1,320	1,300	1,330	1,400	1,440	--------

[a] Values of K depend upon length of time at each temperature.

Greater variation was obtained for the Q values than for the K values. At all frequencies used, dielectrics of high calcia or high titania content had Q values greater than 300; those of high baria content had Q values less than 300. For nearly all of the specimens tested at 3,000 mc/s, the Q values were lower than those measured at lower frequencies. In general, no great improvement in K or Q was obtained by the use of highest purity titania (99.9%) in the preparation of the dielectrics.

Linear thermal expansion was fairly high for all the specimens measured, as shown in table 4. Since local heating to elevated temperatures cracks all these dielectrics, except in thin sections they should be preheated when solder connections are made directly to the metal electrodes on them.

TABLE 4. *Linear thermal expansion*

Specimen designation	Temperature range from 25° C to—						
	100° C	200° C	300° C	400° C	500° C	600° C	700° C
	Percent	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
C2T	0.07	0.18	0.30	0.42	0.555	0.68	0.82
CT	.07	.185	.31	.43	.56	.69	.82
C2T3	.07	.175	.29	.405	.51	.63	.75
CT2	.065	.17	.28	.39	.50	.62	.735
CT6	.06	.15	.25	.35	.45	.555	.655
CB5	.055	.16	.285	.41	.545	.68	.81
BC26	.06	.155	.265	.365	.475	.585	.705
6BC5	.055	.15	.255	.355	.46	.57	.685
BC6	.065	.175	.285	.40	.52	.64	.765
B2C25	.07	.19	.325	.45	.59	.725	.87
BC35	.07	.18	.34	.47	.605	.71	.85

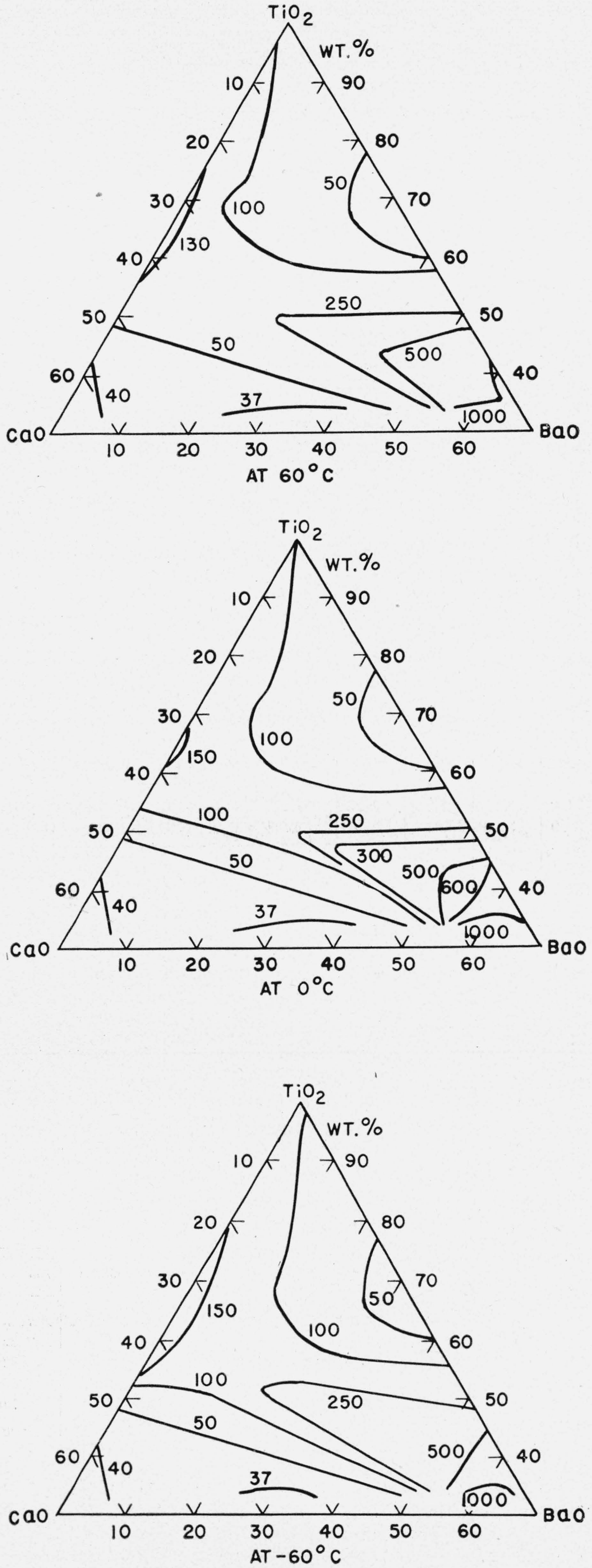

FIGURE 5. *Variation in dielectric constant K with composition at 1 mc/s and at 60°, 0°, and −60° C.*

IV. Summary

Dielectrics having compositions in the system $3CaO:TiO_2$–$BaTiO_3$–TiO_2 can be prepared from mixtures of titanium dioxide with calcium and barium carbonates. Mature dielectrics (less than 0.1% absorption) were obtained by dry-pressing the calcined mixtures and heating the disks thus formed to various temperatures within the range 1,260° to 1,500° C. Matured specimens containing less than 50 percent of titania and greater than about 30 percent of calcia deteriorate in electrical properties after exposure to room conditions for several months.

The dielectric constant, K, varies from 34 for $BaO:4TiO_2$ and $3CaO:TiO_2$ to several hundred for dielectrics having compositions in the region of barium titanate. Most of the temperature coefficients of K are negative. The Q values range from 20 to 10,000 and are lowest for dielectrics of high baria content. K and Q values of some of the dielectrics are affected by their past thermal history, the K decreasing and the Q increasing for several weeks after these specimens are matured.

Relatively high values of the linear thermal expansion (0.65 to 0.81% at 25° to 700° C) were obtained for dielectrics having compositions in all regions of the system.

V. References

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