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Haertling

[15] 3,666,666
[45] May 30, 1972

[54] FERROELECTRIC CERAMIC MATERIALS

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[73] Assignee: **The United States of America as represented by the United States Atomic Energy Commission**

[22] Filed: **Dec. 17, 1969**

[21] Appl. No.: **885,789**

[52] **U.S. Cl.** .....**252/62.9,** 106/39 R, 350/150
[51] **Int. Cl.**.....**C04b 35/46,** C04b 35/48, C04b 35/50, G02f 1/26
[58] **Field of Search**.....252/62.9; 106/39; 350/150

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[57] **ABSTRACT**

An electrooptic ferroelectric ceramic material of a lead lanthanum zirconate titanate solid solution having about 5 to 25 atom percent lanthanum with the ratio of zirconium to titanium varying from about 5/95 to about 95/5, hot-pressed, having an optical transmittance throughout the visible spectrum of about 100 percent for optically polished plates about 0.25 millimeters thick, with an effective birefringence of from about -0.003 to -0.03 at saturation remanence polarization to near zero as the remanent polarization is switched to electrical zero, and an effective electrooptic coefficient at saturation remanence from about 1×10^{-2} to 5×10^{-2} m^2/C, and for memory applications a coercive field from about 2 to 10kV/cm.

7 Claims, 9 Drawing Figures

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OR IN 252/62.9

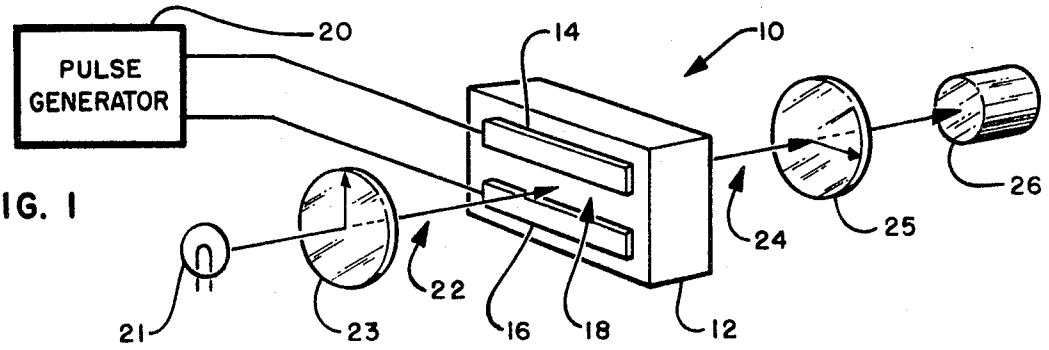

FIG. 1

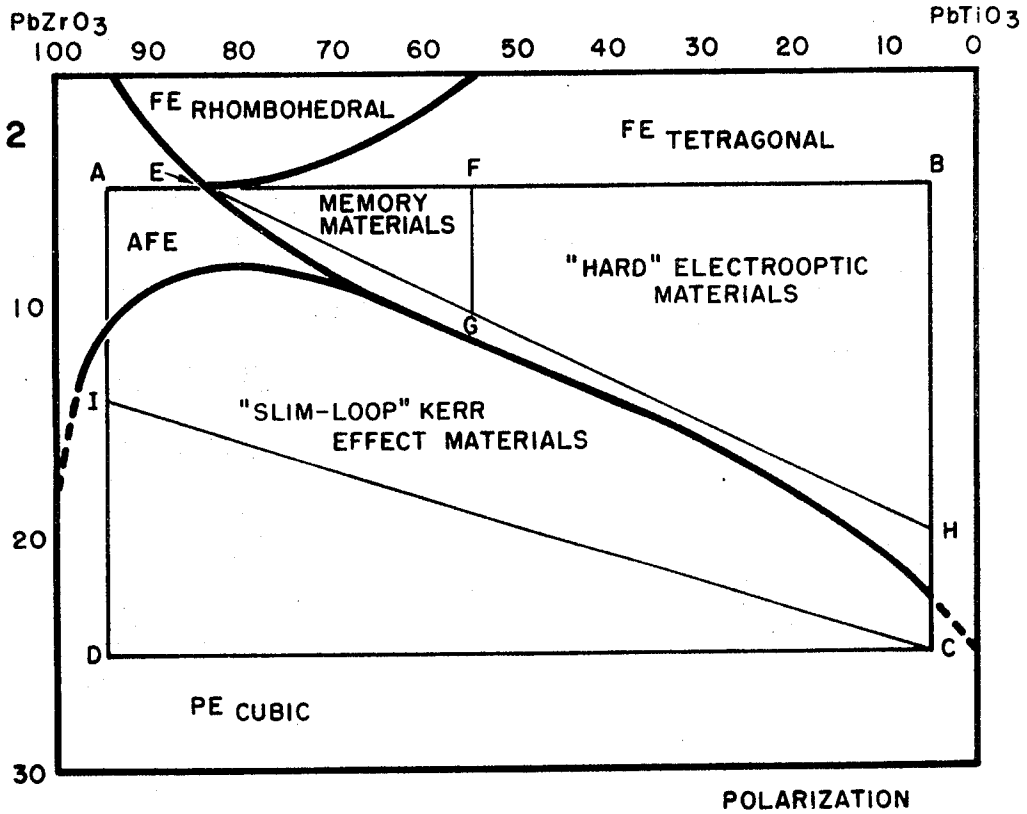

FIG. 2

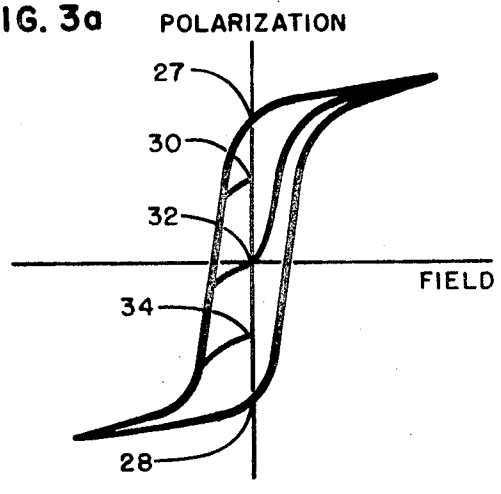

FIG. 3a

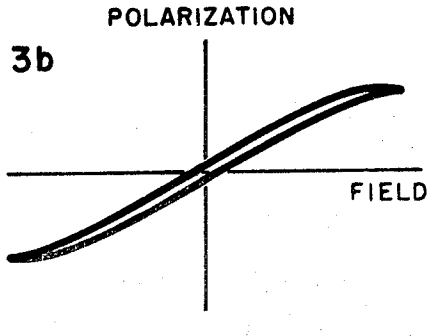

FIG. 3b

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FIG. 4

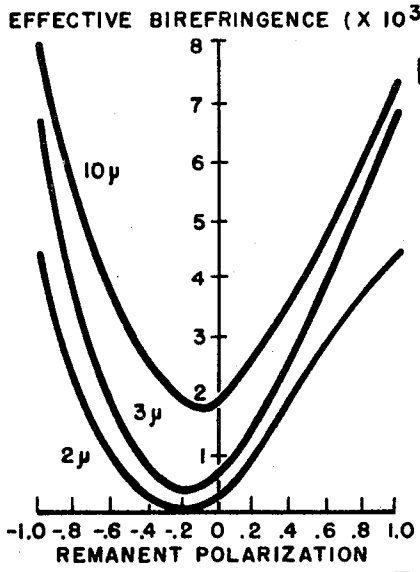


FIG. 5a

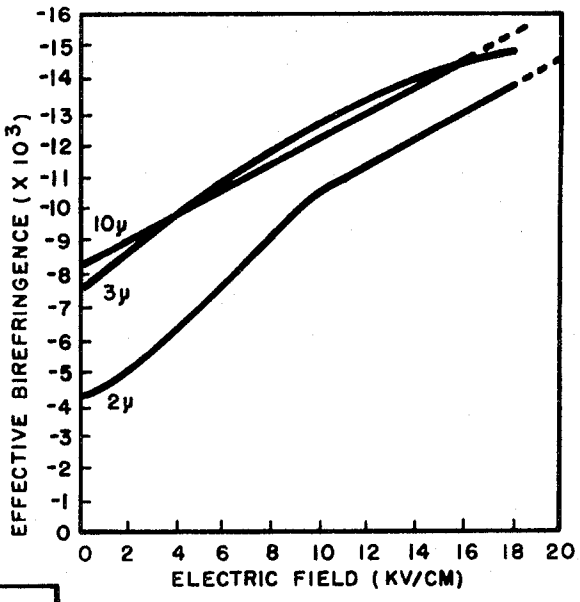


FIG. 6b

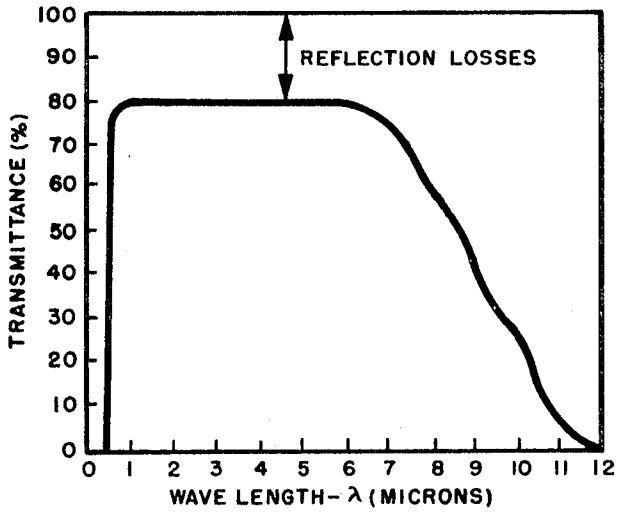


FIG. 5b

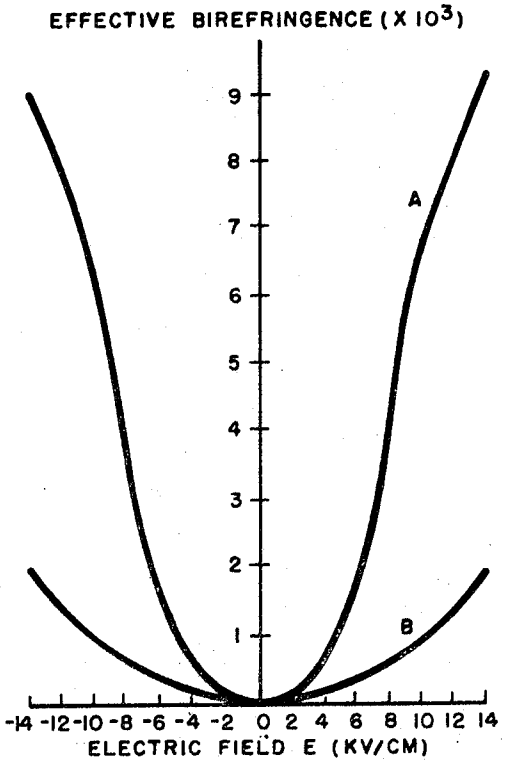
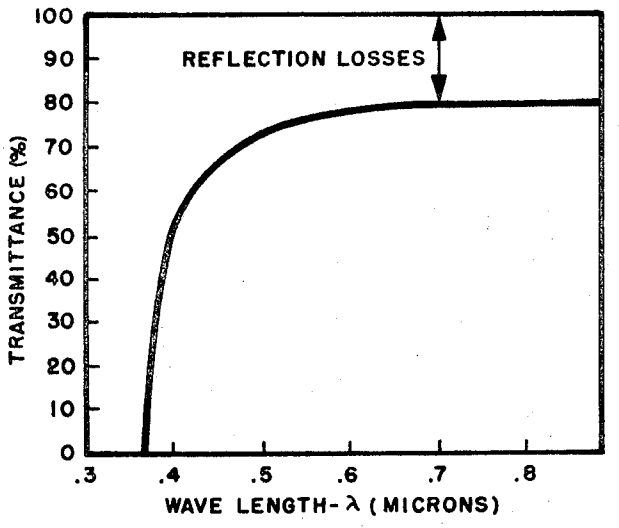


FIG. 6a



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FERROELECTRIC CERAMIC MATERIALS

BACKGROUND OF INVENTION

There is increasing demand for improved electrooptic materials for optical communications, information processing, memory and display systems, that is, materials which exhibit the conventional Pockels or Kerr effects, i.e., reversible variation of birefringence by an applied electric field. Electrooptic materials which exhibit non-volatile memory capabilities, i.e., materials which may be switched from one birefringence value to another and retain the new birefringence when the switching field is removed, are required for optical memories and controlled persistence displays. Also, for memories and controlled persistence displays, it is important that large numbers of small discrete areas be switchable independently in order to achieve a high density of storage sites in a given piece of electrooptic material.

Birefringent, optically uniaxial materials are characterized by two refractive indexes: n_e, the refractive index parallel to the optic axis, and n_o, the refractive index perpendicular to the optic axis. The birefringence of these materials is defined as the difference, n_e-n_o, of the two refractive indexes.

The propagation velocity of light in birefringent materials depends on the orientation of the optical electric vector, i.e., on the light polarization condition. In uniaxially birefringent materials, incident light which is linearly polarized parallel to the optic axis propagates with a velocity c/n_e, and incident light which is linearly polarized perpendicular to the optic axis propagates with a different velocity c/n_o.

Linearly polarized light with its plane of polarization at some angle other that 0° or 90° to the optic axis is resolved into two perpendicular linearly polarized components when it enters the birefringent material. The polarization plane of one compound is parallel to the optic axis; the plane of the other component is perpendicular to the optic axis. Since the propagation velocities of the two components are different, a phase difference develops between the two components as they travel through the birefringent material. This phase difference increases as the light progresses through the material. The total phase difference of the components as they emerge from the material is called the retardation Γ. The retardation obviously depends on the birefringence n_e-n_o (which determines the difference in component velocities) and the material thickness t:

$$\Gamma = (n_e - n_o)t = \Delta n\, t.$$

The polarization condition of the light emerging from the material depends on the retardation. As the two phase-displaced components emerge, they recombine (interfere) to produce elliptically polarized light. The elliptical polarization may vary from circular to linear depending on the retardation. Assuming the incident linearly polarized light is monochromatic with wavelength λ (in air), light emerging from the opposite surface of the material is circularly polarized if Γ is an odd multiple of $\lambda/4$, and the emerging light is linearly polarized if Γ is an even multiple of $\lambda/4$. If Γ is an integral multiple of λ, the polarization planes of the incident and emergent light are parallel. If Γ is an odd multiple of $\lambda/2$ the polarization plane of the emergent light is rotated with respect to that of the incident light by an angle 2ρ, where ρ is the angle between the polarization plane of the incident light and the optic axis.

Electrooptic materials commonly used in the past have been ferroelectric single crystals. These materials exhibit the conventional Pockels or Kerr electrooptic effects. However, with two possible exceptions i.e., gadolinium molybdate and bismuth titanate, single crystals do not exhibit non-volatile optical memory capabilities. The exceptions, gadolinium molybdate and bismuth titanate, have only binary memory capabilities. Also, single crystals have poor localized switching capabilities. When switched in small localized areas, the locally switched areas are surrounded by wide partially switched fringes thus preventing high density localized switching. Other limitations on single crystal electrooptic materials are high cost and difficulties in growing large homogeneous crystals.

Some of the limitations of ferroelectric single crystals in electrooptic applications have been overcome by the discovery of the electrooptic properties of fine-grained, hot-pressed lead zirconate-lead titanate ferroelectric ceramics (Land and Thacher, Proc. IEEE, Vol. 57, No. 5, pp. 751–768, May 1969). For example, these materials become uniaxially birefringent on a macroscopic scale when they are electrically poled (polarized by an external field). Furthermore, their effective birefringence is electrically variable by either applying an external biasing field (the conventional electrooptic effect) or by partially switching the ferroelectric polarization. Variation of the effective birefringence by partial or incremental switching is a property unique to ferroelectric ceramics. Locally switched domains in ceramics remain in their switched orientation after the switching field is removed and the locally switched areas can be "erased" by switching them back to their original orientation. Locally switched areas have narrow fringes, usually only 5 to 10 grain diameters in width, which permits a high density of storage sites on a ceramic plate. Ferroelectric ceramics may be hot-pressed in virtually any size and shape and are relatively inexpensive compared to single crystals. The optic axis orientation in ferroelectric ceramics depends on the direction of the electric poling or switching field, hence it can be switched in any direction. This is not possible in single crystals.

Ferroelectric ceramics may be prepared by sintering at atmospheric pressure as well as by sintering at high pressures (i.e., pressure sintering or hot-pressing). Materials sintered at atmospheric pressure, regardless of material composition and sintering parameters, are inhomogeneous and have relatively high porosity (2 to 6 percent) and, as such, are incapable of use as electrooptic elements or devices due to large and uncontrolled internal light scattering caused by inhomogeneity and porosity. Many ferroelectric ceramics sintered at atmospheric pressure have a generally yellowish, opaque appearance regardless of size and plate thickness. The optical transmittance of these materials may be typically less than one percent (neglecting reflection losses) for plates 0.05 mm thick and any light which is transmitted will generally be completely depolarized due to internal scattering. This depolarization and low optical transmittance is inherent in all commonly available atmospheric-pressure sintered ferroelectric ceramics, including lead zirconate-lead titanate compositions previously known in the art and including those having rare earth element additives of any amount such as those having 10 atom percent or less.

Ferroelectric ceramics produced by high pressure sintering techniques (i.e., hot-pressing techniques) may have significantly increased homogeneity and decreased porosity (essentially zero) from that of ferroelectric ceramics sintered at atmospheric pressure. Hot-pressed ferroelectric ceramics may exhibit higher optical transmittance as well as the additional capabilities of non-volatile optical memory, high density localized switching and the like as previously described for fine-grained, hot-pressed lead zirconate-lead titanate ceramics (Land and Thacher, IEEE Proc., Vol. 57 No. 5, pp. 751–768, May 1969).

For the purposes of this invention, optical transmittance may be defined as the ratio of light intensity transmitted by an optical material or device into a specific detector, to the light intensity incident on the optical material or device measured by the same detector. This ratio is always expressed as a percentage in this application.

Conventional hot-pressed ceramics including fine-grained lead zirconate-lead titanate solid solutions, exhibit undesirable scattering of transmitted light which limits their optical transmittance and requires that they be used in thin plates (thickness typically 0.1 mm or less). For example, optically polished plates 0.25 mm thick may have a maximum optical transmittance of about 5 percent (neglecting reflection losses); plates 0.05 mm thick may have a maximum optical transmittance of about 60 percent (neglecting reflection losses). These maximum transmittances occur at the red end

of the visible light spectrum; scattering dispersion reduces the optical transmittances to essentially zero at the violet end of the light spectrum.

In many applications it is highly desirable to use plates thicker than 0.1 mm for mechanical strength and rigidity and to increase the range of electrically variable retardation (product of birefringence and plate thickness). In other applications it is desirable to use optical networks comprised of two or more electrooptic devices in series. Therefore, ferroelectric ceramic electrooptic materials with greatly increased transmittance (reduced light scattering) are required for these applications and desirable for all electrooptic applications.

The birefringence of fine-grained, hot-pressed lead zirconate-lead titanate solid solutions may be about −0.02 at saturation remanence and it may vary to about −0.01 at zero remanent polarization. This means that the birefringence may be varied over a range of about 50 percent of its value at saturation remanence by partial or incremental switching of the remanent polarization. It is highly desirable for optical memory and controlled persistence display applications that the range of birefringence variation as a function of remanent polarization be increased. In this material the effective electrooptic coefficients ($r_{eff}/\gamma T_{33}^{T}$) may be about $1 \times 10^{-2} m^2/C$ and the coercive field (field at which the polarization can be switched from saturation remanence to zero) may be about 12kV/cm.

SUMMARY OF INVENTION

In view of the above, it is an object of this invention to provide a ferroelectric ceramic composition having optical transmittance throughout the visible spectrum.

It is a further object of this invention to provide a ferroelectric ceramic composition capable of having optical transmittance throughout the visible spectrum of about 100 percent.

It is a further object of this invention to provide a ferroelectric ceramic composition having an effective birefringence dependent on remanent polarization with a range extending from some maximum at saturation remanence to about zero near zero remanence.

It is a further object of this invention to provide a ferroelectric ceramic composition having a high effective electrooptic coefficient and a relatively low coercive field.

It is a further object of this invention to provide a ferroelectric ceramic composition having all of the above properties as well as the desirable properties of conventional hot-pressed ferroelectric ceramics.

Various other objects and advantages will appear from the following description of the invention, and most novel features will be particularly pointed out hereinafter in connection with the appended claims.

It will be understood that various changes in the details and materials, which have been herein described and illustrated in order to explain the nature of the invention, may be made by those skilled in the art.

The invention comprises a hot-pressed ferroelectric ceramic solid solution composed of lead lanthanum zirconate titanate with about 5 to 25 atom percent lanthanum substituted for the lead and with the zirconium to titanium ratio varying from about 5/95 to about 95/5.

DESCRIPTION OF DRAWING

Various characteristics of the ferroelectric material of the present invention are shown in the accompanied drawing wherein:

FIG. **1** is a perspective and somewhat schematic view of a ferroelectric ceramic optical system;

FIG. **2** is a partial phase diagram of the lead lanthum zirconate titanate solid solution system;

FIGS. **3***a* and **3***b* are graphs of polarization versus applied electric field for ferroelectric ceramic materials of this invention;

FIG. **4** is a graph of effective birefringence versus remanent polarization for different grain sizes of a ferroelectric material of this invention with a hysteresis loop as shown in FIG. **3***a*;

FIG. **5***a* is a graph of effective birefringence versus electric field for different grain sizes of the material used in FIG. **4**;

FIG. **5***a* is a graph of effective birefringence versus electric field for ferroelectric material as shown in FIG. **3***b*; and

FIGS. **6***a* and **6***b* are graphs of typical transmittance versus wavelength for materials of this invention.

DETAILED DESCRIPTION

A typical electrooptic device **10** is shown in FIG. **1** in somewhat simplified and diagrammatic form with exaggerated dimensions. Electrooptical device **10** may include a ferroelectric ceramic plate or member **12** composed of the material of this invention and prepared as described below.

Plate **12** may have any convenient electrode arrangement or pattern to provide a desired optical output, such as those described in the Land and Thacher article referred to hereinabove, for example, a pair of electrodes **14** and **16**. Electrodes **14** and **16** may be disposed on a surface of plate **12** on opposite sides of a polarization area or information location **18**. An electric field may be produced between electrodes **14** and **16** in location **18** of plate **12** by an appropriate power source or pulse generator **20**. Pulse generator **20** may be any appropriate electrical pulse source which may produce pulses of a desired polarity and amplitude and switch domains of plate **12** disposed between electrodes **14** and **16** at location **18** in one or more directions. A source of light **21** may be positioned near plate **12** so as to impinge light, such as shown by arrow **22**, against location **18** and through plate **12**. The light source may be any conventional ordinary or white light source, such as an incandescent or mercury arc lamp, or for certain applications a monochromatic or narrow band light source, such as a laser or filtered light source, which is capable of projecting a desired beam of light against location **18**. The light source may also include standard collimating means including special lens or fiber optic systems. The light source preferably includes a linear polarizer element **23** between the light source and location **18** so as to polarize the light impinging on location **18** some prescribed direction. A linear analyzer **25** and a suitable photosensitive device **26** may be aligned with the light beam emerging from plate **12**, such as shown by arrow **24**, to sense the amplitude of the light beam emerging from plate **12** and polarized in the direction of the linear analyzer. Linear analyzer **25** is generally positioned so as to have its polarization axis at right angles to that of linear polarizer **23**. The electrooptical device **10** may thus effectively control the color or intensity of light from a white light source or intensity of light from a monochromatic source as the emerging beam impinges upon photosensitive device **26**.

Plate **12** is an optically uniaxial ferroelectric material having a multiplicity of grains with uniform nominal grain diameters typically about **10** microns or less, a relative density greater than about 99 percent theoretical, and maximum homogeneity, light transmittance, surface smoothness. The grain diameter needed to achieve the desired electrically controlled optical properties may be dependent upon the particular ferroelectric composition and the hot-pressing parameters used. It has been found that in order to achieve these properties, the ferroelectric material must be prepared by hot-pressing or pressure sintering techniques.

An optically uniaxial ferroelectric ceramic for purposes of this invention, is one in which the poled or polarized ceramic is effectively optically uniaxial, i.e., it exhibits the macroscopic symmetry properties of an optically uniaxial, birefringent crystal. The individual grains or crystallites of an optically uniaxial ceramic may exhibit either uniaxial (tetragonal, rhombohedral and hexagonal) symmetry or the generally biaxial (orthrhombic, monoclinic, and triclinic) symmetry. A poled ferroelectric ceramic is generally optically birefringent. With the individual crystallites exhibiting negative birefrin-

gence, the electrical polar direction is the fast axis of the ceramic. The effective birefringence in a ferroelectric ceramic plate depends upon the degree or magnitude of electrical poling in a given direction, i.e., whether the ceramic is fully or only partially poled in a particular direction. The orientation of the optic axis depends upon the direction of electrical poling in the ceramic. It has been found that electric control of the light transmission properties of device **10** may be effected by varying the magnitude of the ferroelectric polarization at location **18** in plate **12** by the application of an external electric field by pulse generator **20**. The pulse amplitude and pulse width may be adjusted to produce partial or incremental switching of the ceramic polarization. The pulse amplitude is adjusted to produce the required switching speed; the pulse width is adjusted to produce the desired change in polarization. Incremental switching of the ceramic polarization produces corresponding incremental changes in the effective birefringence of the ceramic plate. Typical pulse widths and pulse amplitudes may vary from about 0.1 microsecond to 100 microseconds and about 0 to about 30 kilovolts per centimeter depending on the electrode separation distance, plate thickness and composition.

Ferroelectric ceramic plate **12**, in accordance with this invention, is a ferroelectric ceramic $Pb_{1-x}\ La_x\ (Zr_y\ Ti_z)_{1-x/4}O_3$, where x is between about 5 and about 25 atom percent with a ratio of y/z from about 5/95 to about 95/5. This compositional series is a lead lanthanum zirconate titanate (hereinafter referred to as PLZT) solid solution having lanthanum substituted for lead in the prescribed amounts. Compositions may also be prepared according to an alternate formula; i.e., $Pb_{1-3x/2}\ La_x\ (Zr_y\ Ti_z)\ O_3$. However, where this formula is used, an additional quantity of lead oxide, ranging from 0.1 to 8 weight percent, must be added to the original batch weight.

The phase diagram of the (Pb, La)(Zr, Ti) O_3 system is given in FIG. **2**. Compositions or solid solutions covered by this invention are included within the rectangular area ABCD. Compositions which are ferroelectric tetragonal phase and fall within the area EFG may exhibit good memory material characteristics while those which fall within the area FBHG may exhibit good "hard" (high coercivity) conventional electrooptic material characteristics. Paraelectric cubic phase as well as mixed paraelectric-ferroelectric compositions (having a coercive field of about 0) falling in the remaining area, AEHCD, and principally those in area AEHCI may exhibit good Kerr effect characteristics. As the lanthanum substituent increases, the magnitude of the Kerr effect may decrease.

For example, ferroelectric ceramic material prepared in accordance with this invention, having a Zr/Ti ratio of 65/35 and having a lanthanum substitute of from about 5 to 8 atom percent may exhibit a polarization hysteresis curve similar to that shown in FIG. **3***a* while a material having lanthanum substituted at greater than about 9 atom percent may have a polarization hysteresis curve similar to that shown in FIG. **3***b*. As the lanthanum substitute is increased, the hysteresis curve of FIG. **3***a* becomes more slanted with respect to the polarization axis and becomes narrower until reaching the condition shown in FIG. **3***b*. The materials having lanthanum substituted up to about 8 atom percent exhibit a plurality of stable, polarization states between the remanent polarization states 27 and 28. These states are shown by way of example as 30, 32 and 34, 32 being at zero polarization. Many materials may exhibit 10 or more stable polarization states between saturation remanent and zero polarization. As the lanthanum substitute is increased, the saturation remanent polarization decreases in amplitude and approaches zero polarization. The group of materials having a hysteresis characteristic similar to that shown in FIG. **3***a* may have coercive fields varying from about 2 to 10 kilovolts per centimeter.

Ferroelectric ceramic material prepared in accordance with this invention, having a Zr/Ti ratio of from 55/45 to 5/95 and having a lanthanum substitute of from 12 to 20 atom percent respectively (within the area FBHG of FIG. **2**), may exhibit a polarization hysteresis loop curve similar to that shown in FIG. **3***a* with increased values of coercive field ranging from 10kV/cm to 40kV/cm. Materials in this compositional range are not readily switched by an electrical pulse from one polarization state to another (such as envisioned in a memory device) and hence may be utilized in a conventional electrooptic mode of operation after the material is initially and uniformly poled.

The above materials may exhibit effective birefringences varying from 0 to as much as about −0.003 to −0.03 (depending upon composition and hot-pressing parameters), the latter birefringence being at saturation remanence polarization with the former being at zero polarization. The variation of effective birefringence with varying remanent polarization is illustrated in a typical example in FIG. **4** for the composition PLZT 8/65/35 (where 8/65/35 designates atom percents of La, Zr and Ti respectively). Generally, the maximum effective birefringence at a given polarization increases with decreasing lanthanum substitute. The three curves of FIG. **4** apply to three different grain sizes, 2μ, 3$\mu$and 10μ, of the PLZT-8/65/35 composition. As the grain size increases, the effective birefringence at saturation remanent polarization (normalized remanent polarization of 1.0 and −1.0) also increases. Also, the minimum birefringence (near zero remanent polarization) increases with increasing grain size. The minimum birefringence of the 2μgrain size material is zero which results in a 100 percent range of birefringence variation.

The dependence of the effective birefringence of the three samples of FIG. **4** on bias electric field E is shown in FIG. **5***a*. The ceramic plates were first poled to saturation remanent polarization (+1.0 of FIG. **4**), and then the bias field was applied in the saturation (positive) direction. It is apparent that the birefringence increases with increasing bias field and to fields as high as 10kV/cm the increase is approximately a linear function of the applied field. The electrooptic coefficients (r_{eff}/ϵ_{33}^T) are all larger than any previously measured for fine-grained lead zirconate-lead titanate solid solutions.

The curves of FIG. **5**(*b*) apply to two compositions each having a polarization hysteresis curve similar to that of FIG. **3***b*. Curve A of FIG. **5***b* is a plot of effective birefringence vs. bias electric field for the composition PLZT-9/65/35; curve B is a similar plot for the composition PLZT-11/65/35. Note that the composition PLZT-9/65/35 falls on the FE tetragonal-PE cubic phase boundary of FIG. **2**. For this reason, one would expect the birefringence variation with electric field to be greater for this material than for the PLZT-11/65/35 composition which falls well inside the PE cubic phase of FIG. **2**.

A ferroelectric ceramic plate made of a material within the above compositional ranges may exhibit an optical transmittance throughout the visible spectrum of about 100 percent (after correcting for reflection losses) with optically polished surfaces and a plate of about 0.25 millimeters or less. As the thickness of the plate increases the transmittance may decrease, for example, with a plate 1.5 millimeters thick the transmittance may be about 50 percent. Some materials may exhibit a 100 percent transmittance with plates slightly greater or less than 0.25 millimeters thick, depending upon the composition and hot-pressing parameters, however, this variation in transmittance with plate thickness may be minimal. FIGS. **6***a* and **6***b* illustrate the transmittance of a typical ferroelectric ceramic (PLZT 8/65/35) within the compositional range noted above over the visible light spectrum and infrared spectrums respectively.

These ferroelectric ceramic compositions may be prepared by (1) weighing lead oxide, zirconia, titania and lanthana powders, (2) wet mixing the powders in a suitable liquid medium such as distilled water, (3) drying the wet mixed powders, (4) calcining the dried powder mixture at a temperature of about 900° C. for about 1 hour, (5) granulating or wet ball milling of the calcine to break down the partially sintered particle aggregates, (6) drying the wet milled calcine, and (7) compressing the resulting powder into a slug. As stated previously, it has been found that in order for the finished ceramic plate to exhibit the above noted properties, that the slug must then be

further processed by hot-pressing at a temperature from about 800° C. to about 1,300° C. for about 1 to 64 hours at a pressure of from about 500 to 20,000 psi in an appropriate hot-pressing apparatus. The grain size may be controlled by selecting raw materials oxide powders which are of high chemical purity (generally greater than about 99.2 percent) and by the proper selection of hot-pressing conditions of temperature, time and pressure. After hot-pressing, it is desirable that the finished slug be sliced into thin wafers or plates and the major surfaces polished to an optical quality finish. The plates may then be annealed at from about 500 to 700° C. for about 15 minutes, cooled to room temperature, electrodes positioned or plated thereon and the plate polarized to a desired uniform initial polarization.

Ferroelectric ceramic materials thus formed and within the compositional ranges noted above exhibit the high optical transmittance, wide range of variable effective birefringence, high effective electrooptic coefficients and low coercive fields desired in electrooptic devices. The properties exhibited by these materials may be orders of magnitude better than any previously known ferroelectric ceramic electrooptical material. The uniform optical transmittance over the visible spectrum and the wide range of effective birefringence permits use of such ferroelectric material in optical displays requiring the production of color over the entire visible spectrum. This latter feature is further enhanced by the high level of optical transmittance with plate thicknesses many orders of magnitude greater than previous materials.

Commercially available oxide raw materials having chemical purity as noted above may commonly include iron in quantities greater than 500 parts per million. It has been discovered that the optical clarity of the hot-pressed ferroelectric ceramic materials may be improved by insuring that the iron content of the raw material oxides is below about 300 parts per million.

Examples of typical hot-pressed lead lanthanum zirconate titanate materials prepared in accordance with this invention are listed in the following table illustrating some of their electrical and optical characteristics. All materials listed exhibited about 100 percent optical transmittance except PLZT 2/65/35 which exhibited about 25 percent transmittance for samples 0.25 millimeters thick.

Composition (PLZT)	E_c (kV/cm)	$\epsilon_{33}^T/\epsilon_o$	K_p	P_r ($\mu C/cm^2$)	Tan δ (Poled) (%)
2/65/35	13.5	652	0.450	39.3	2.8
6/65/35	7	1210	0.525	32.0	2.5
8/65/35	5	3380	0.647	31.0	2.4
9/65/35	4	4050	low	12.0	5.3
11/65/35	<2	3900	0.0	2.0	5.6
12/65/35	<2	2200	0.0	0.0	4.6
14/65/35	<2	1450	0.0	0.0	2.3
8/10/90	36	355	0.210	29.0	1.0
18/10/90	16	866	0.320	24.0	1.1
16/20/80	16	890	0.325	24.4	1.2
14/30/70	15.5	1025	0.352	25.2	1.1
12/40/60	15	1284	0.382	25.2	1.2
8/40/60	21	884	0.413	30.5	1.2
8/53/47	16	2020	0.488	27.7	1.5
9/60/40	7	2200	0.430	24.8	3.8
6/80/20	9	832		31.8	2.0
8/80/20	4			2.0	
8/70/30	6	4050	0.446	26.0	4.7

What is claimed is:

1. An optical material having electrically variable birefringence consisting essentially of a ferroelectric ceramic of $Pb_{1-x}La(Zr_yTi_z)_{1-x/4}O_3$ falling within the area ABCD of FIG. 2 where x is between about 5 and 25 atom percent with a ratio of y/z from about 5/95 to about 95/5 and prepared by hot-pressing at temperatures from about 800° C. to about 1,300° C. for about 1 to 64 hours at a pressure of about 500 to 20,000 psi, said ceramic having an optical transmittance in at least a portion of the visible spectrum of about 100 percent after correction for reflection losses with material about 0.25 millimeters thick.

2. The material of claim 1 having about 100 percent transmittance after correction for reflection losses in the electromagnetic spectrum from about 0.7 to about 7 microns.

3. The material of claim 1 having an effective birefringence of from about −0.003 to −0.03 at saturation remanence polarization varying to near zero as remanent polarization is switched to electrical zero and having an effective electrooptic coefficient at saturation remanence from about 1×10^{-2} to about 5×10^{-2} m^2/C.

4. The material of claim 3 falling within the area EFG and having a coercive field from about 2 to 10kV/cm and having a plurality of stable polarization states between zero polarization and saturation remanent polarization.

5. The material of claim 3 falling within the area FBHG of FIG. 2 and having a coercive field from about 10 to 40kV/cm.

6. The material of claim 3 falling within the area AEHCD and having a coercive field of about zero.

7. The material of claim 3 falling within the area AEHCI and having a coercive field of about zero.

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