Ferroelectric Ceramic Technology for Sensors

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Ceramic Operations Manager

PCB Piezotronics

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Overview

- Ferroelectricity versus Piezoelectricity
- Historical Background
- Ferroelectric Ceramic Composition Engineering
- Ceramic Manufacturing Process

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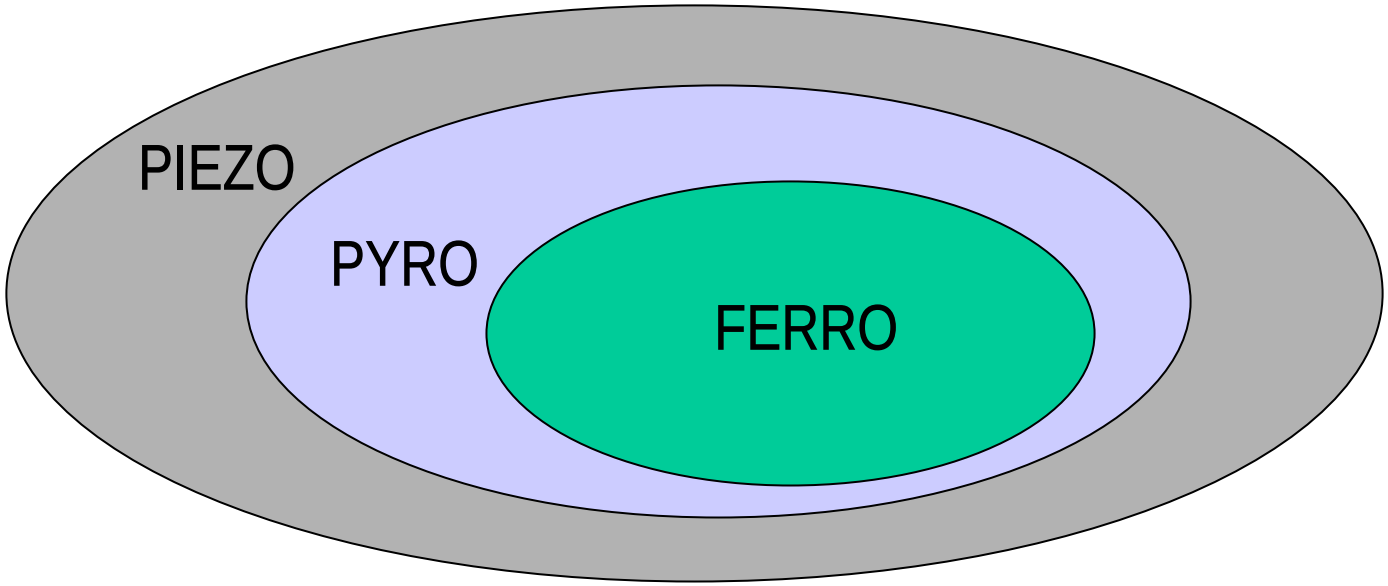
Ferro- vs. Piezoelectricity



- Piezoelectrics – no center of symmetry in crystal structure
- Pyroelectrics – Piezo with spontaneous dipole moment
- Ferroelectrics – Pyro with spontaneous dipoles that are reversible

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Historical Background

- Piezoelectricity - Quartz
  - J. & P. Curie, 1880
- Pyroelectricity - Tourmaline
  - Greeks, ca. 315 B.C.
- Ferroelectricity - Rochelle Salt
  - Valasek, 1921

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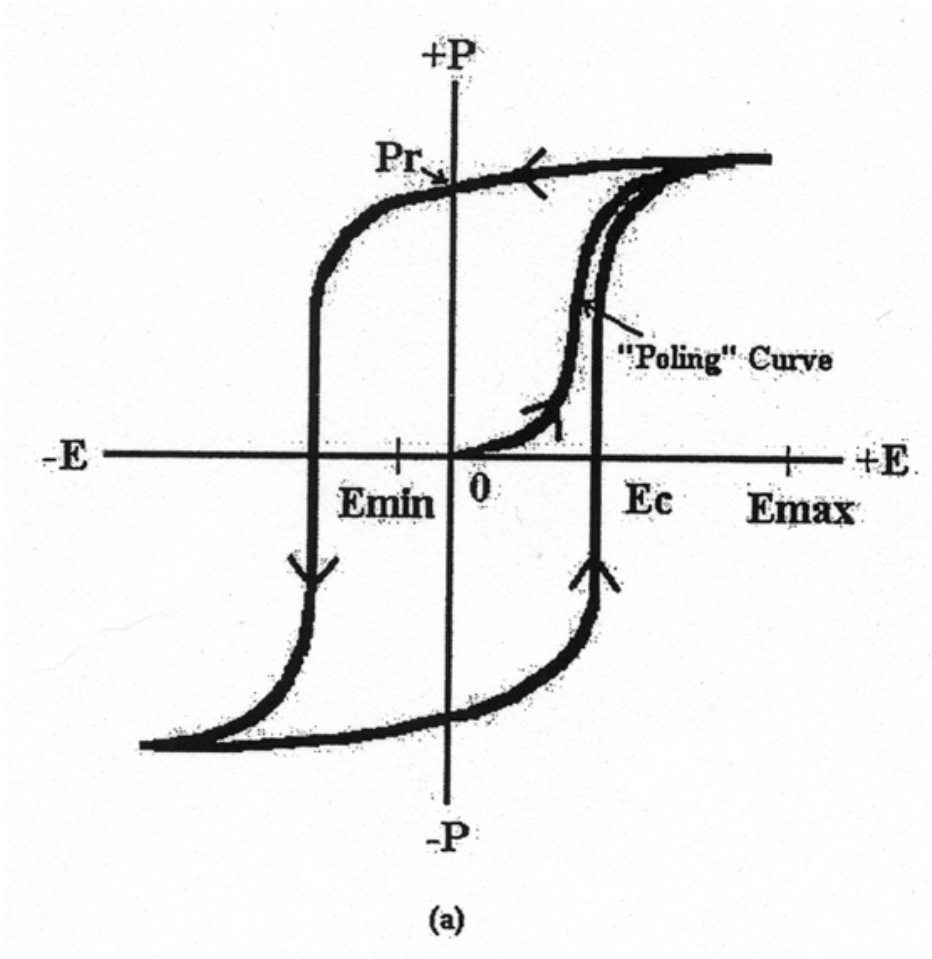
FE Hysteresis Loop



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Ferroelectric Ceramics

- Barium Titanate - first FE ceramic
  - High dielectric constant determined to be due to ferroelectricity
- Lead Zirconate Titanates (PZT)
  - Most widely used FE ceramics
- Bismuth Titanates
  - High temperature application (T_C~680°C)
- Many others
  - Lead metaniobate
  - Lead titanate, and various combinations with PT

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Typical Sensor Crystal Properties

	Quartz	PZT-5A
Charge Output	2.3 (d_{11})	380 (d_{33})
Diel. Constant	4.5	1800
Voltage Output	62 (g_{11})	25 (g_{33})
Temp Stability	Stable	Pyro
Time Stability	Stable	Aging Effects
Polar Axis	Fixed	Determined by processing

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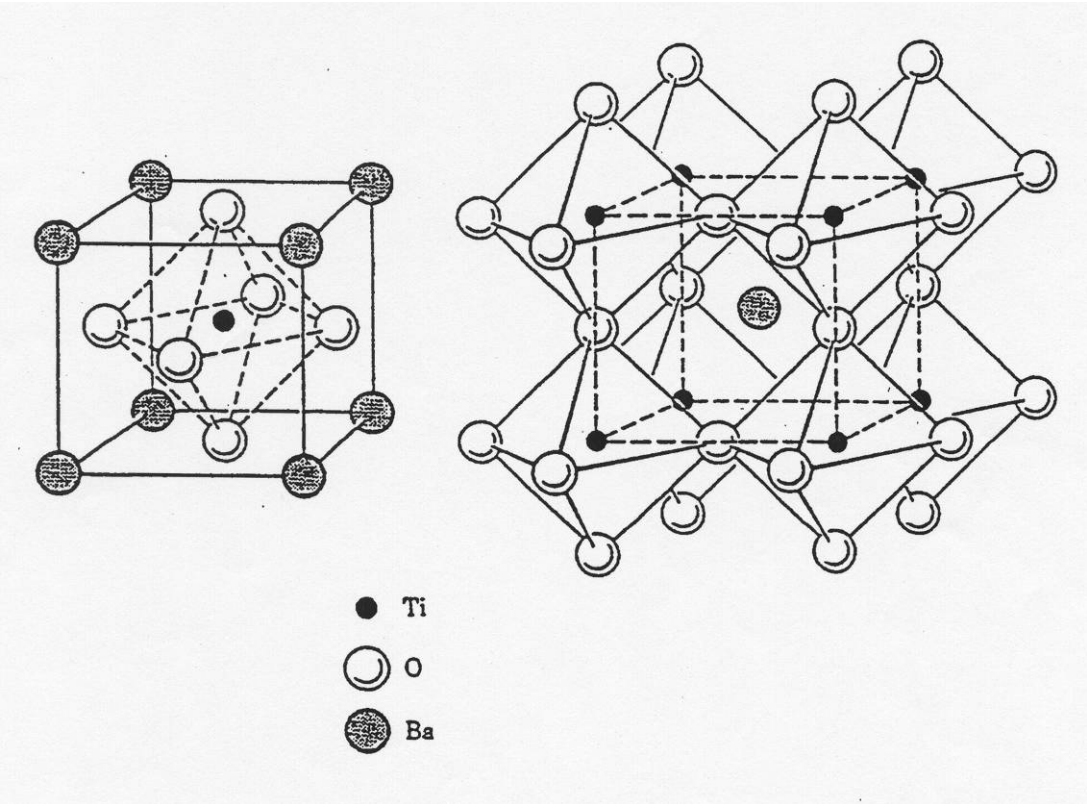
Ferroelectric Ceramics



- PZT ceramics are based on the perovskite (ABO_3) crystal structure, $Pb(Zr/Ti)O_3$

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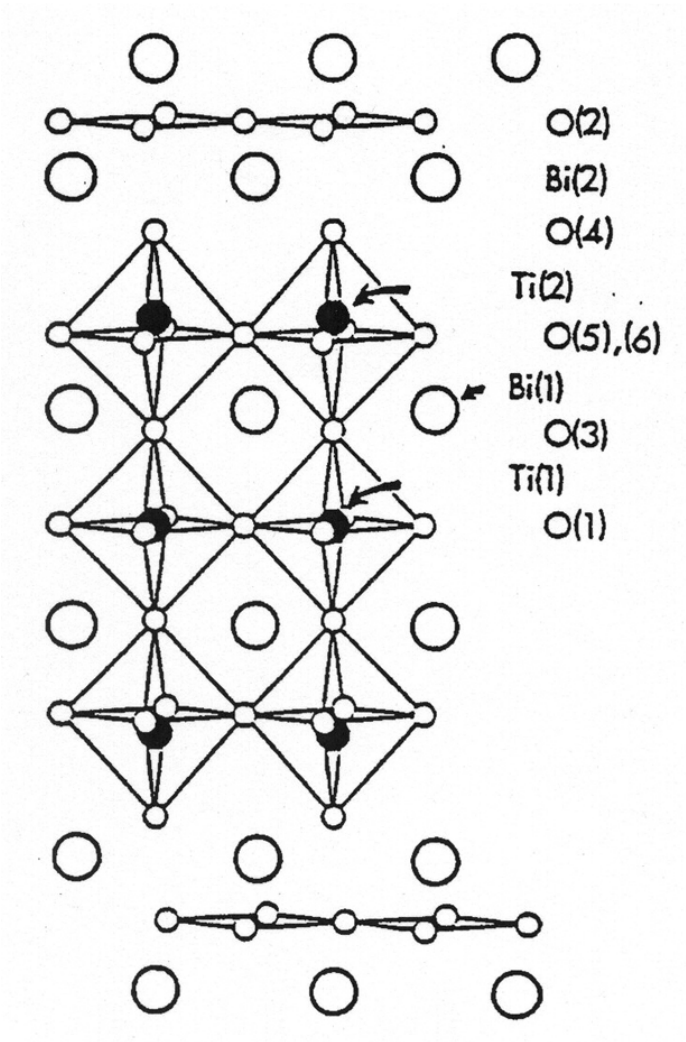
Ferroelectric Ceramics



- High temperature bismuth titanates form in layer structures (Bi_2O_2) – ($Bi_2Ti_3O_{10}$)

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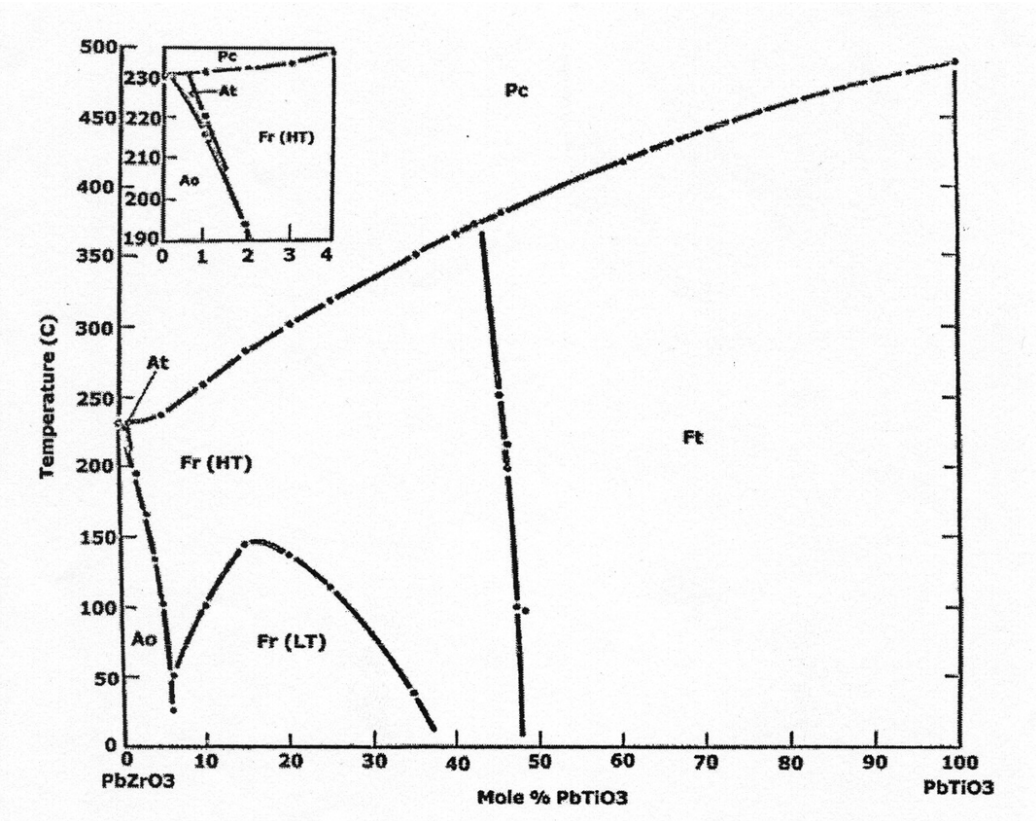
PZT Ceramics



- $PbZrO_3$ – $PbTiO_3$ phase diagram
- ABO_3, where A=Pb, B=Zr/Ti
- "Morphotropic phase boundary" exists at specific Zr/Ti ratio, results in maximum PE properties

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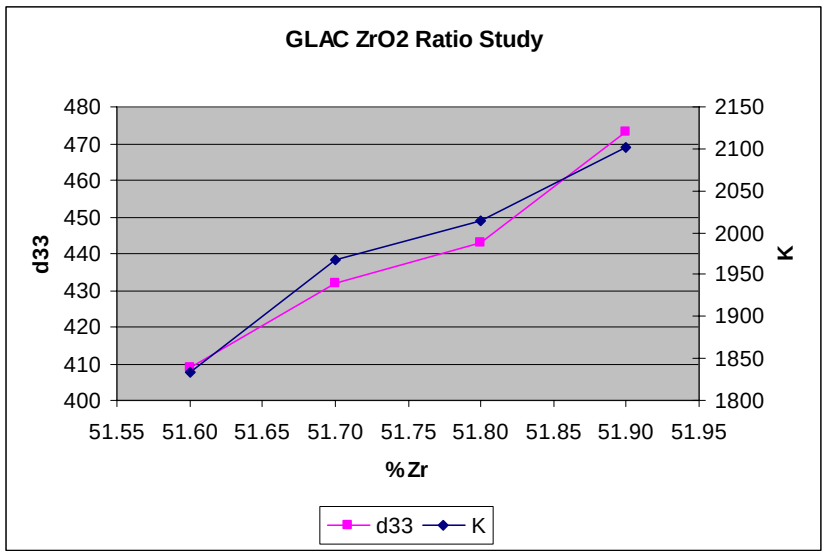
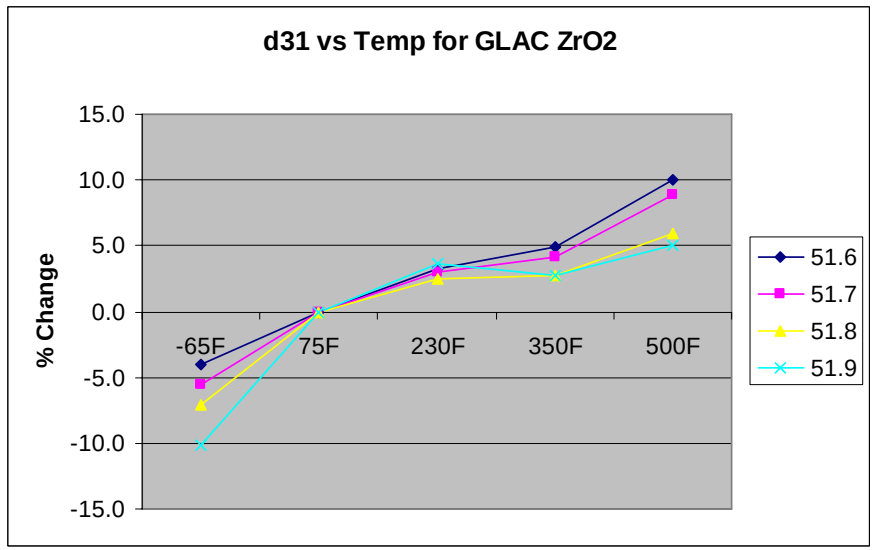
PZT Ceramics

- Major advantage is the ability to slightly modify the composition to tailor the properties
- Small adjustments to Zr:Ti ratio alter properties





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PZT Ceramics

- Properties can also be tailored by substitutions – "doping"
- Doping changes oxygen vacancy concentration
- "Soft" and "Hard" PZT's, depending on dopant type

Dopant	Replaces	Type	Effects
Nb^{5+}	Zr,Ti^{4+}	Donor	"Soft" PZT; Increased I.R., K^T, d_{33}; dielectric losses increase; lower Q_m
Fe^{3+}	Zr,Ti^{4+}	Acceptor	"Hard" PZT; Decreased I.R., K^T, d_{33}; dielectric losses decrease; higher Q_m

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Ceramic Manufacturing Process

Specialty Raw Materials

- Electronic grade raw materials are used
- Each new raw material lot requires qualification

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Ceramic Manufacturing Process

Powder Preparation

Weighing

Calcining

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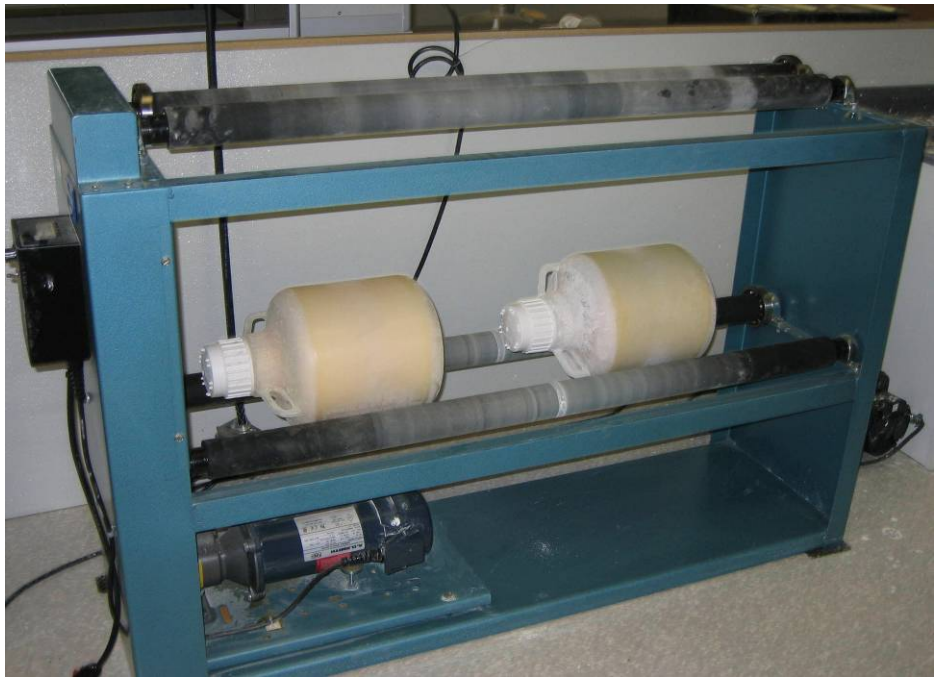
Ceramic Manufacturing Process

Powder Preparation



Milling

Granulating

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Ceramic Manufacturing Process

Powder Characterization

HORIBA LA-930 for Windows(TM) [WET(LA-930)] Ver.3.45
LA-930 system for Windows

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Crystal Department
3425 Walden Avenue
Depew, NY 14043
Phone: 716-684-0001

Filename :PZT EXP15-10 milled T1average<C>
ID# :200604191432174
Sample Name :EXP 15-10 milled
Material :PZT
Source :PCB
Lot Number :15-10

Circulation Speed :3
Ultra sonic :01:00 (7)
Laser T% : 81.5(%)
Lamp T% : 83.9(%)

Form of Distribution :Standard
Distribution Base :Volume
S.P. Area : 42460(cm^2 /cm^3)
Median : 1.6965(μm)
Mean : 1.9047(μm)
Mode : 1.8500(μm)
Span : 1.4972

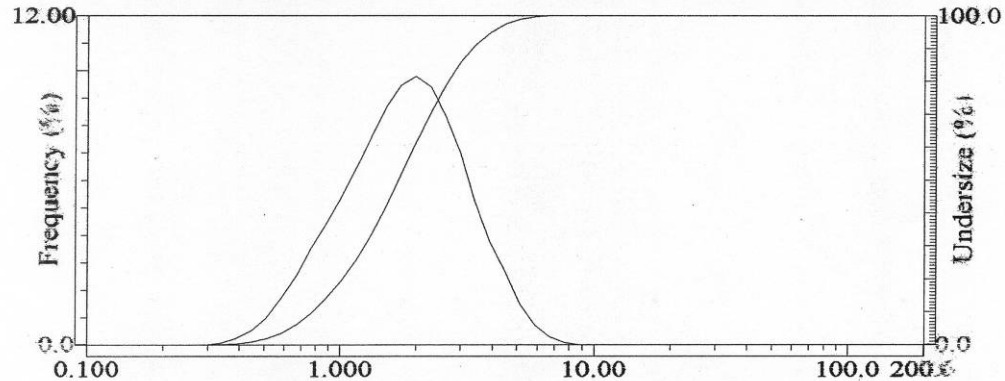
Calc. Level :3
R.R.Index :170a001i
Variance : 1.0768($μm^2$)
S.D. : 1.0377(μm)
CV : 54.4800
Geo. Mean : 1.6483(μm)
Chi-2 : 0.044204

Diameter on %

:(1)5.000 (%)- 0.6336(μm)	(6)60.00 (%)- 1.9501(μm)	
(2)10.00 (%)- 0.7770(μm)	(7)70.00 (%)- 2.2519(μm)	
(3)20.00 (%)- 1.0206(μm)	(8)80.00 (%)- 2.6573(μm)	
(4)30.00 (%)- 1.2438(μm)	(9)90.00 (%)- 3.3169(μm)	
(5)40.00 (%)- 1.4659(μm)	(10)95.00 (%)- 3.9492(μm)	

% on Diameter

:100.0 (μm)- 100.000(%)	5.000 (μm)- 98.672(%)	
50.00 (μm)- 100.000(%)	4.000 (μm)- 95.251(%)	
10.00 (μm)- 100.000(%)	3.000 (μm)- 86.151(%)	
7.000 (μm)- 99.947(%)	2.000 (μm)- 61.792(%)	
6.000 (μm)- 99.688(%)	1.000 (μm)- 19.071(%)	



- Particle size distribution analysis is used to verify process conditions

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Ceramic Manufacturing Process

Batch Qualification Testing

- Sample crystals from each batch are processed and tested
- Properties measured at room temp and over extended temp range

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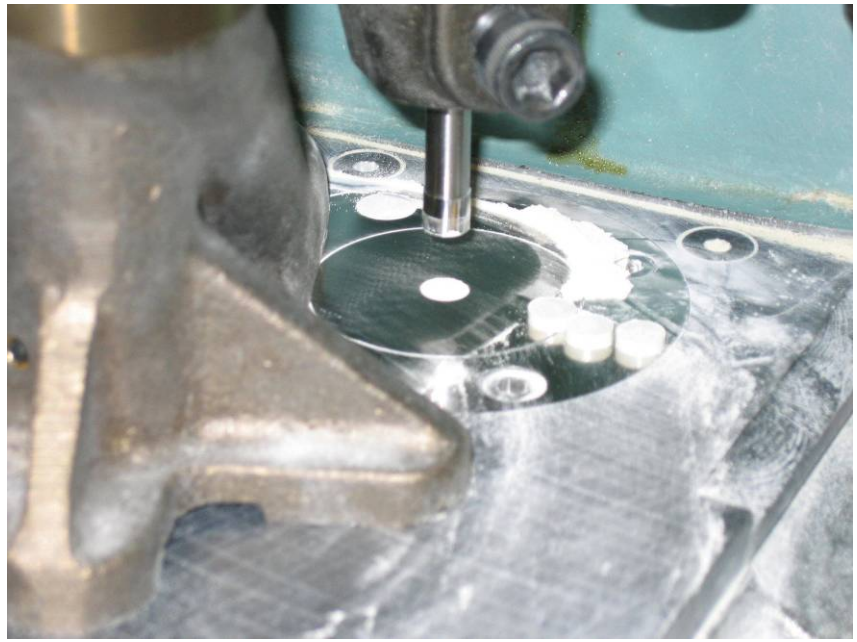
Ceramic Manufacturing Process

Tablet Processing



Dry Pressing

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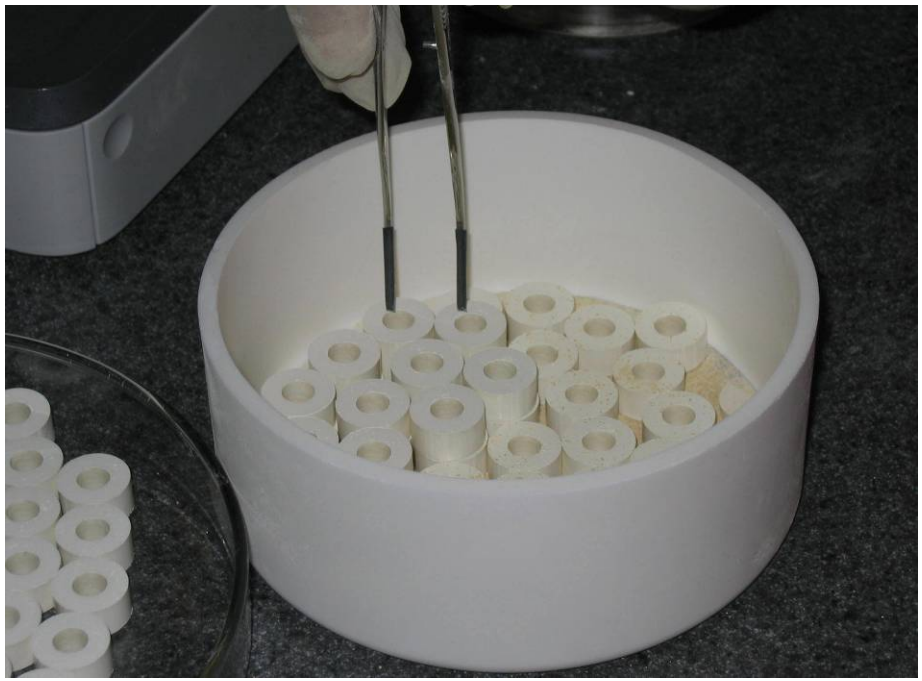
Ceramic Manufacturing Process

Tablet Processing



Loading Crucibles

Ceramic Firing

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Ceramic Manufacturing Process

Preparing Ceramics for Polarization

Lapping

Silver Plating

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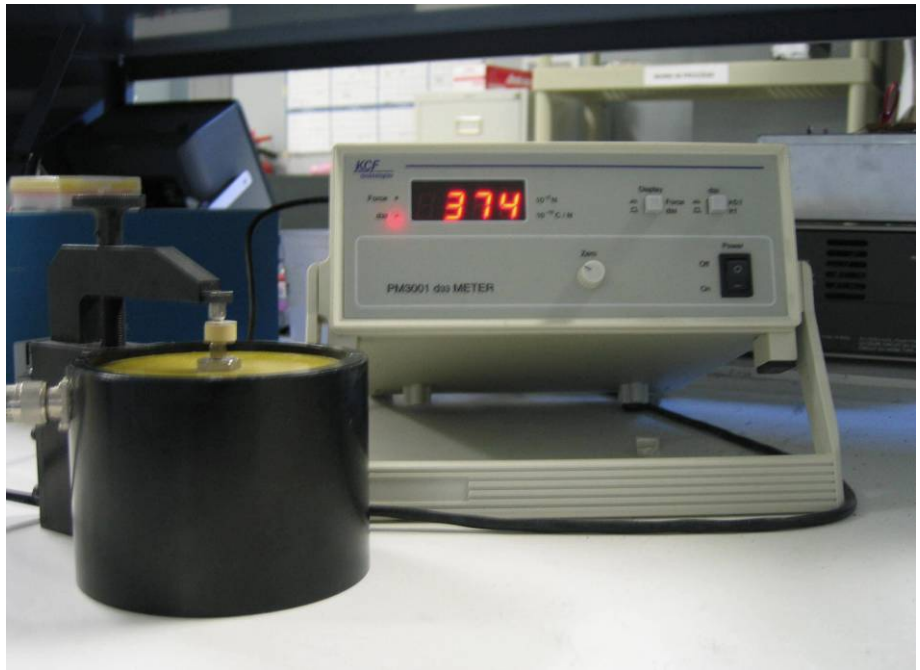
Ceramic Manufacturing Process

Polarization

Poling



d_{33} Test

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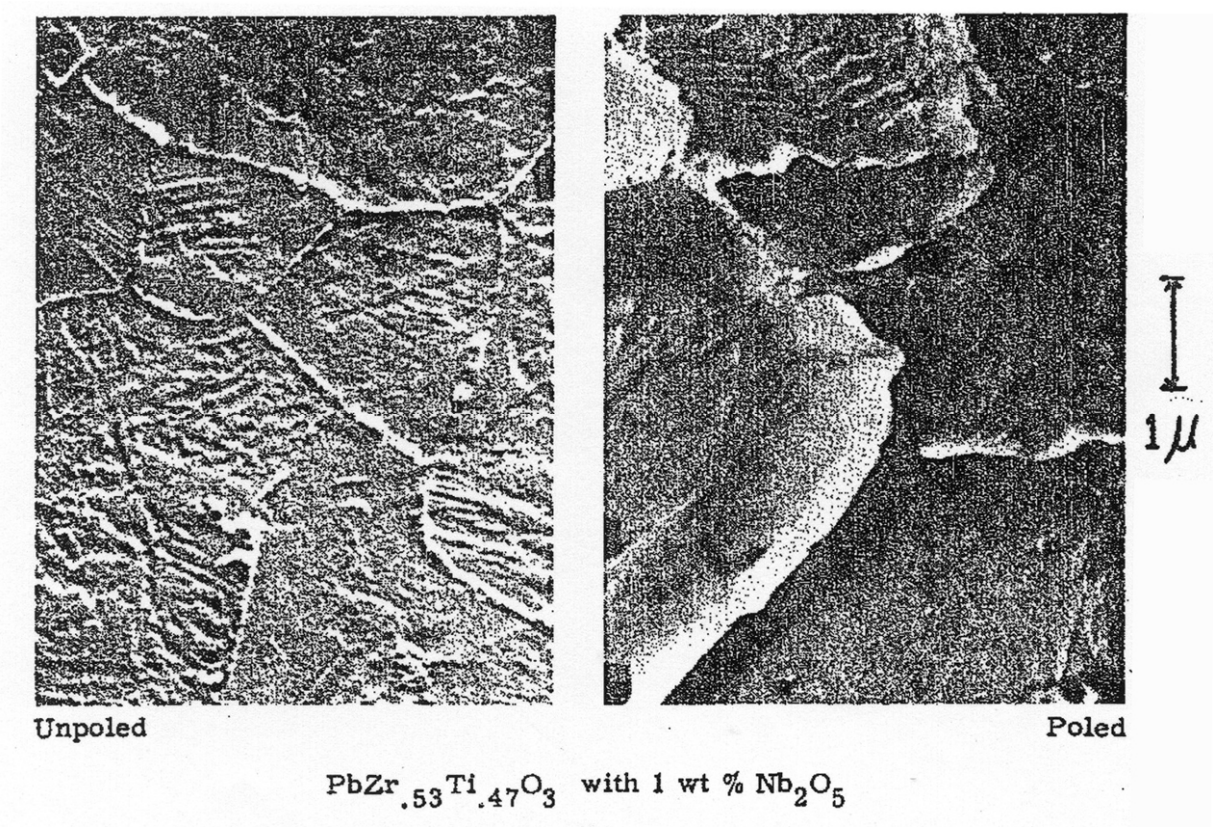
Ceramic Manufacturing Process

Polarization



- Left: Unpoled material has randomly oriented domains
- Right: Application of DC field reorients the domains

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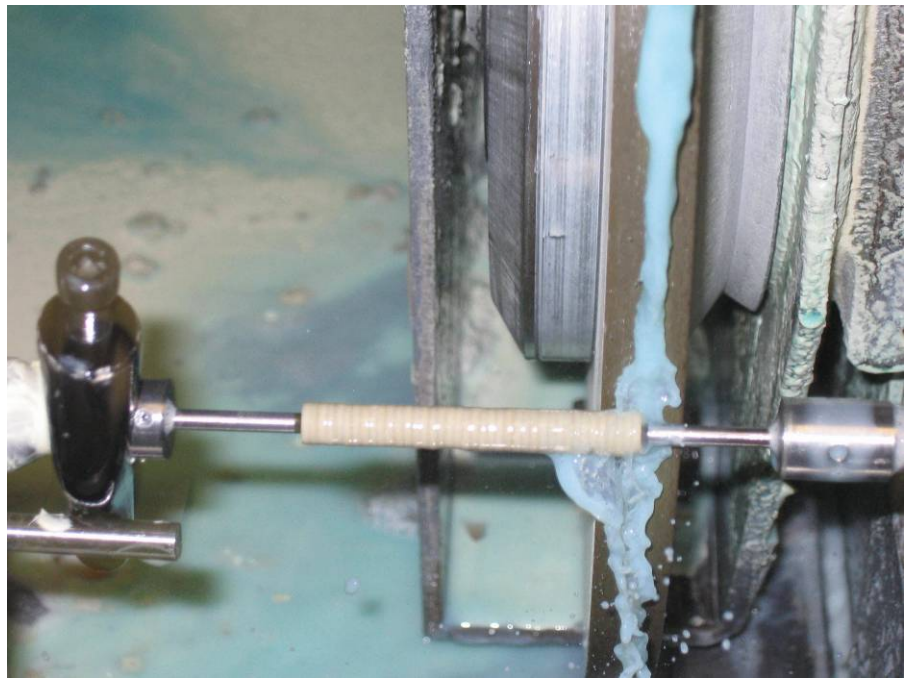
Ceramic Manufacturing Process

Machining of Polarized Pieces

Core Drilling



OD Grinding

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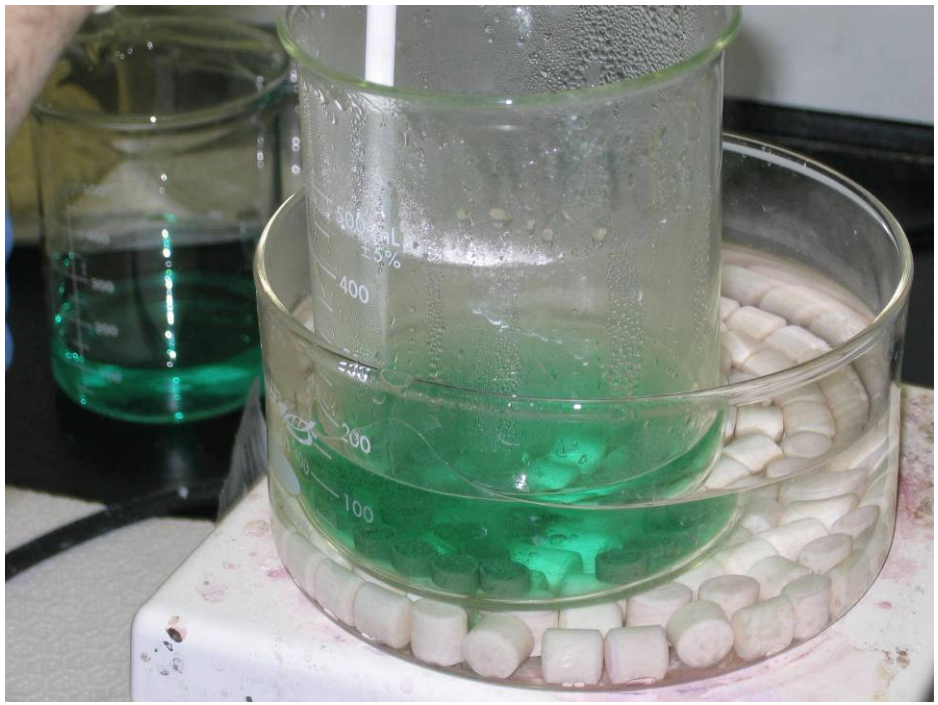
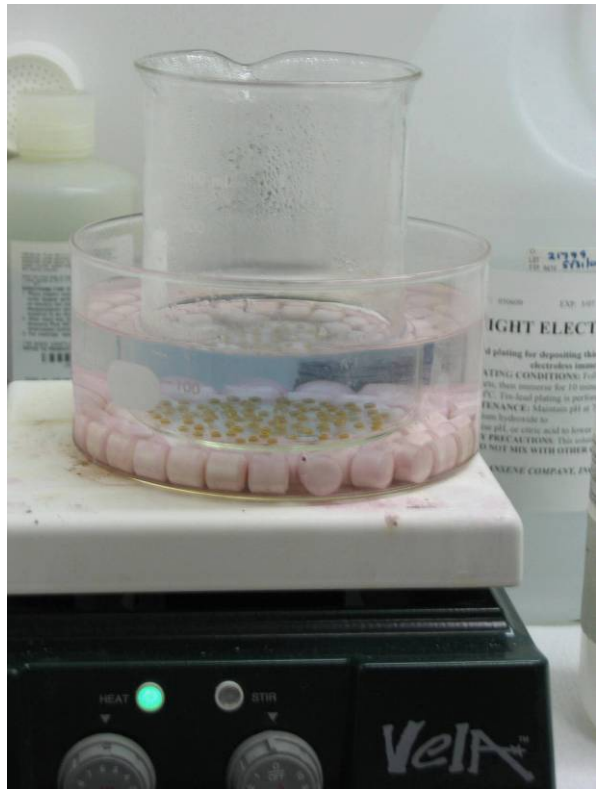
Ceramic Manufacturing Process

Plating Crystals



Electroless Nickel Plating



Gold Plating

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Ceramic Manufacturing Process

Final Shaping

Finish Lapping

Slotting

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Ceramic Manufacturing Process

Testing and Inspection

Cap Test

I.R. Test

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Ceramic Manufacturing Process

Testing and Inspection

Visual Inspection

Mechanical Inspection

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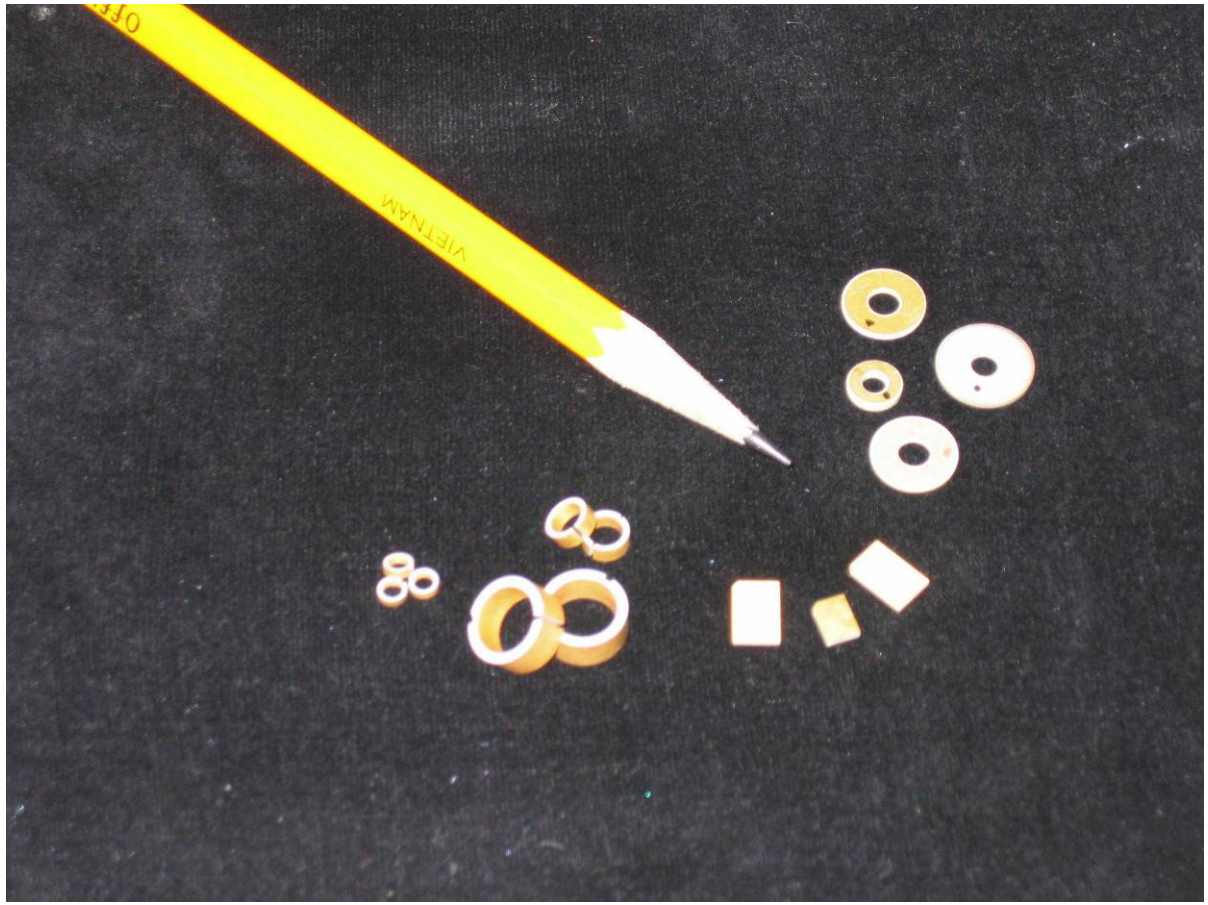
Ceramic Manufacturing Process

Finished Ceramic Crystals



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