

Advanced Manufacturing of a Novel Functional Material

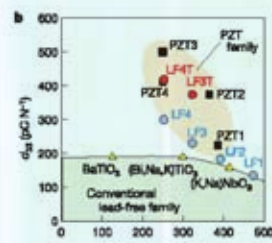


Sandia National Laboratories

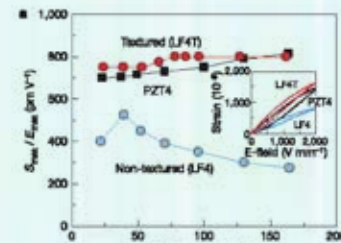
Christopher DiAntonio, Pin Yang, Alex Roesler, Mike Winter, Audrey Blea, Tom Chavez, Mark Rodriguez, Nelson Bell, George Samara, Heidi Schulze, Science, Technology, and Engineering (ST&E), Advanced Manufacturing Science and Technology, Disruptive "Game Changing" Manufacturing Science and Technology Sandia

DEVELOP ALTERNATIVES FOR LEAD-BASED ELECTROCEAMICCOMPOSITIONS

- Sensors, Actuators, Explosively Driven Power Supply, etc.....
- Workhorse - PbTiO₃-PbZrO₃ (i.e. PZT-system)
 - Perovskite Crystal Structure
 - Morphotropic Phase Boundary
 - High activity of lead cation
 - Conventional Processing Methods
 - 60% Lead Containing Family of Ceramics
- Growing health concerns and environmental regulations
- Alternatives have never been fully realized



(Ref: Y. Saito, et al. "Lead-free piezoceramics," Nature 432 84-86 (2004))



MICROSTRUCTURE ENGINEERING OF ELECTROCEAMIC MATERIALS

- Target - Develop an advanced, low cost manufacturing process for a non-lead based microstructurally engineered ferroelectric ceramic material
 - Microstructure engineering through texture modifications
 - Template induced texturing process for a bulk ceramic
- Fabrication of a "Functional" Material via a Novel Process
 - Synthesis of templated seed crystals
 - Morphologically Controlled Templates
 - Preferably oriented polycrystals
 - Fused Salt Synthesis Technique
 - Texture Engineering - Mutual Orientation of the Crystallographic lattices of the individual grains.
 - "Reactive" Templated Grain Growth

- House of Cards
 - Random Grain Orientation

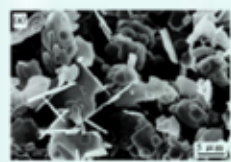
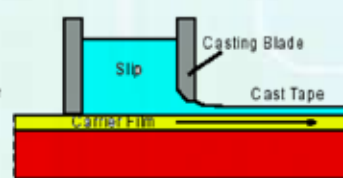


- Deck of Cards
 - Preferential Grain Orientation {001}

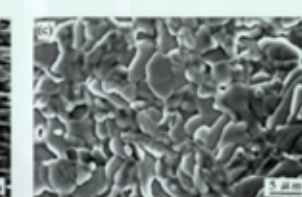
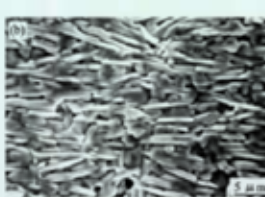
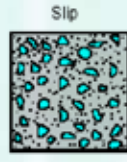


TEXTURE INDUCED FORMING PROCESS AND METHODS

- Texture development - Highly localized shear
- Induced Shear Stresses result in particle alignment
 - Preferred Stress Direction



Perpendicular to the Ceramic (polished and thermally etched).

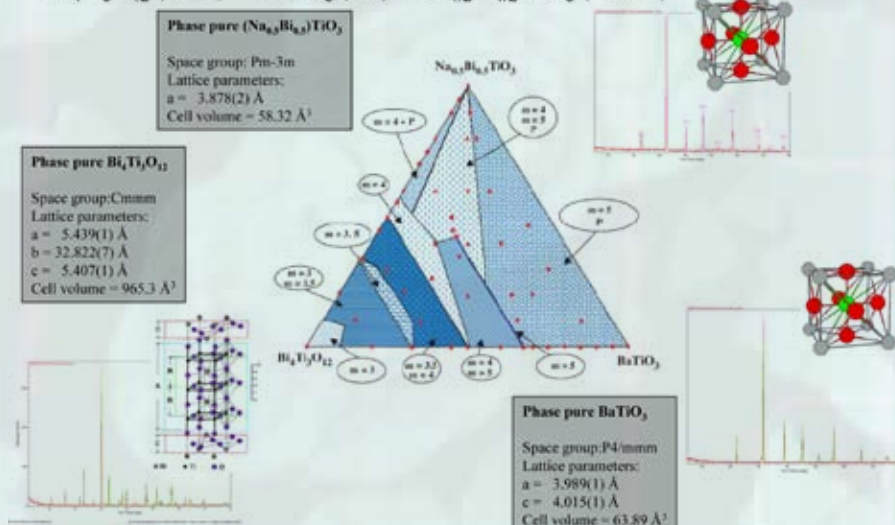


Parallel to the Ceramic (polished and thermally etched).

(Ref: T. Takeuchi, T. Tani, and Y. Saito, Jpn. J. Appl. Phys. Vol. 38 (1999), pg. 5555)

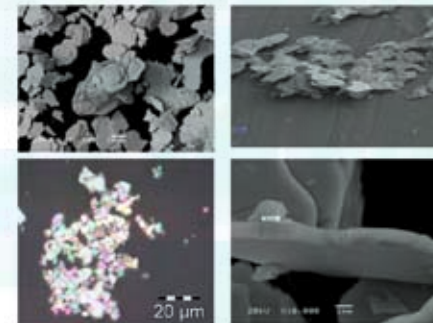
POTENTIAL TERNARY SYSTEM: Na_{0.5}Bi_{0.5}TiO₃-Bi₄Ti₃O₁₂-BaTiO₃

- Bi₄Ti₃O₁₂ (BTO) - BaTiO₃ (BT) - Na_{1/2}Bi_{1/2}TiO₃ (NBTO)

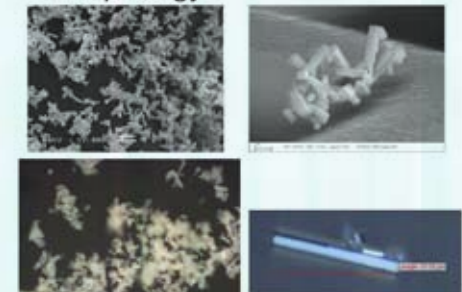


Bi₄Ti₃O₁₂ AND Sr_{1-x}Ba_xNb₂O₆ TEMPLATE SEED CRYSTALS

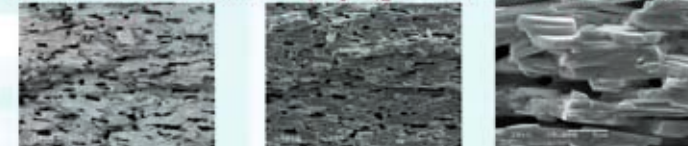
- Bi₄Ti₃O₁₂ (BTO) Seed crystals express a platelet like morphology



- Sr_{1-x}Ba_xNb₂O₆ - Seed crystals express a fiber/whisker like morphology



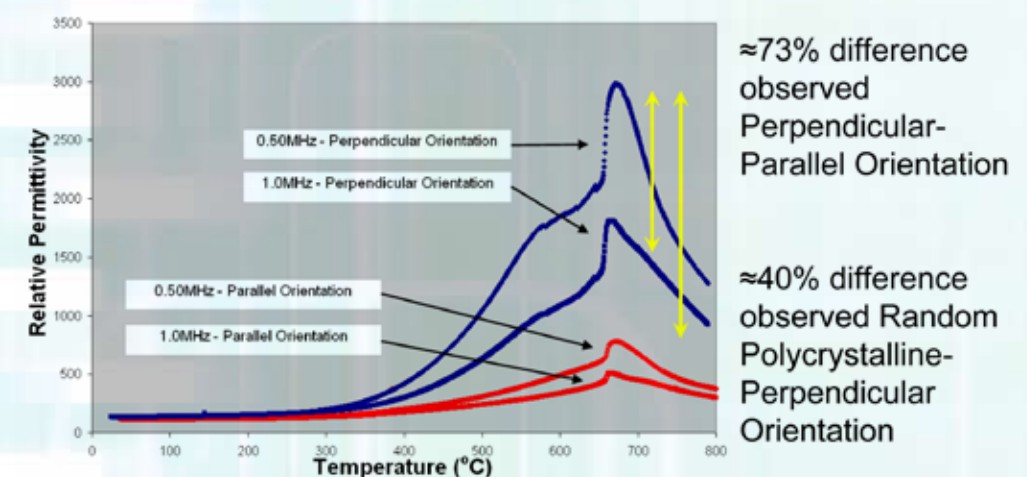
- Textured polycrystalline Bi₄Ti₃O₁₂ ceramic microstructures



ENHANCED DIELECTRIC PROPERTIES INDUCED BY TEXTURED MICROSTRUCTURE

- Weak-Field Dielectric Properties - BTO System

Temperature (°C)	Frequency (MHz)	Orientation	Relative Permittivity	% Difference
670	0.5	Parallel	778	
670	1	Parallel	503	
670	0.5	Perpendicular	2960	73.89%
670	1	Perpendicular	1803	72.10%
670	0.5	Random Polycrystalline	1769	40.64%
670	1	Random Polycrystalline	1088	39.66%



~73% difference observed Perpendicular-Parallel Orientation

~40% difference observed Random Polycrystalline-Perpendicular Orientation

R&D SIGNIFICANCE TO SANDIA AND THE NATION

- Success would transform the lab into one of the nationally and internationally recognized forerunners in the fabrication of texture engineered ceramic materials and simultaneously overcome the dependence on lead-based ferroelectric compositions
- Emerging needs rely heavily on maintaining the momentum to develop low cost advanced manufacturing processes
 - intermingled in a novel process that produces a functional material that meets the needs.
- Enhancing materials properties from lead-free electroceramic compositions
 - Approach single-crystal like benefits from low-cost, widely utilized manufacturing capabilities
- Eliminating the environment and toxicity issues surrounding leaded compositions.
- Enhance the ability to provide improved capabilities for;
 - pulsed power generation
 - advanced sensing technology for homeland security endeavors
 - superior sonar materials for Navy systems
 - novel 'smart' materials
 - higher resolution ultrasounds for medical diagnostics