Case Western Reserve University EST. 1826

Effects of dopant on depoling temperature in modified $BiScO_3 - PbTiO_3$

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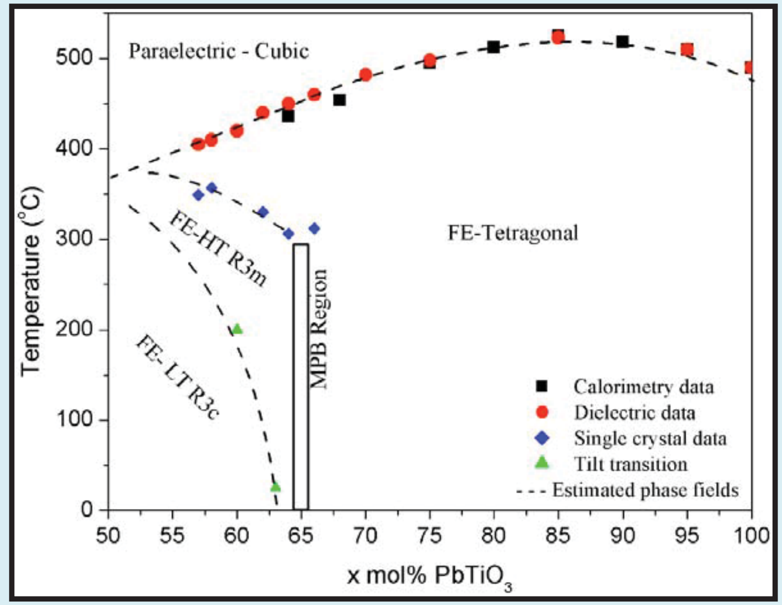
Introduction

- Piezoelectrics for high temperature applications
  - Fuel/gas modulation, ultrasonic drilling, etc.
- Tolerance factor (*t*) acts as guide for selection of non-PT member
- $BiScO_3 – PbTiO_3$:
  - T_c: 450°C, d_{33}: 460 pm/V for morphotropic phase boundary (MPB) composition

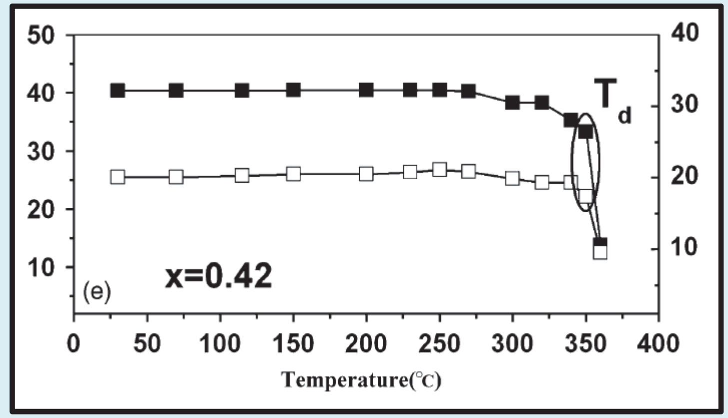


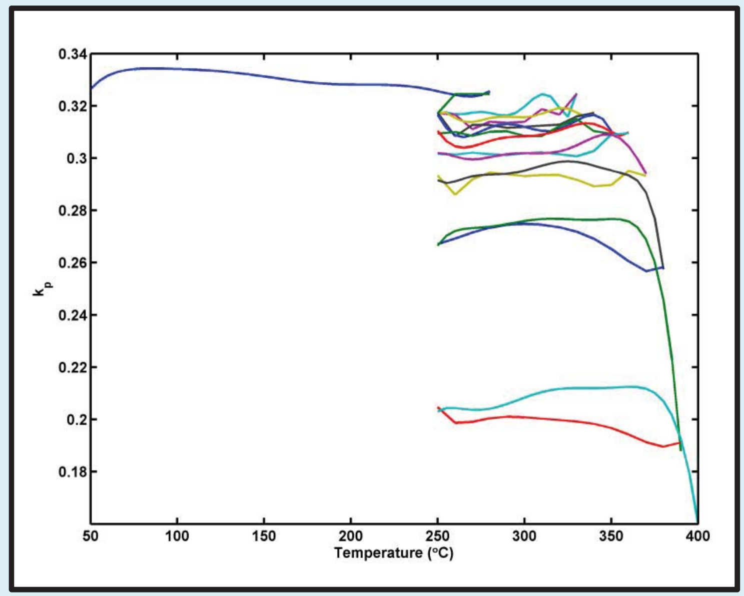
- A-site modification: La, Ba
- B-site modification: Ga, Mn, Zr, $Zn_{0.5}Ti_{0.5}$, Nb, etc.
- DC conductivity, tanδ, d_{33}, T_c, T_d, etc.

Phase diagram – Eitel *et al,* J. Appl Phys., 2004

A different metric

- Curie temperature (T_c) doesn't tell whole story
- Many piezoelectric materials depole before T_c
- Why do they depole? Domain rotation, phase transitions, inhomogeneities
- Dope to change depoling temperature

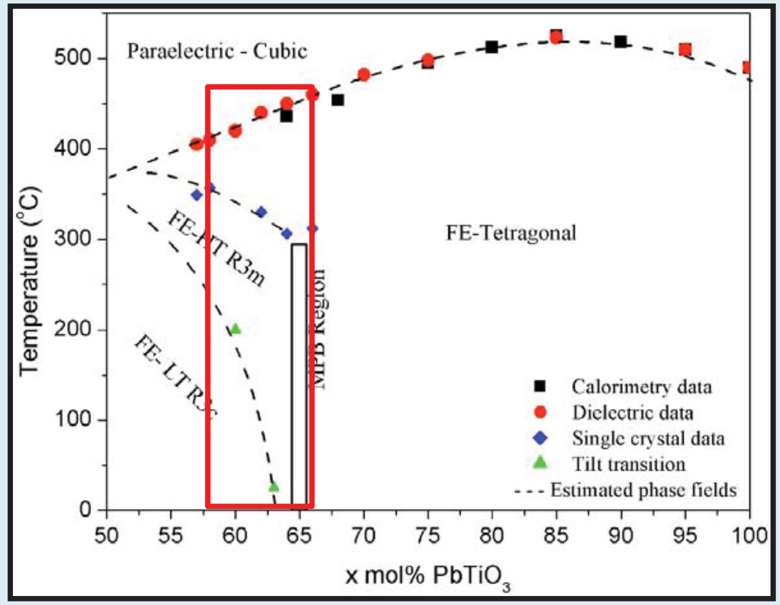




Upper right – Zhang *et al,* J. Am. Cer. Soc., 2010

Compositions

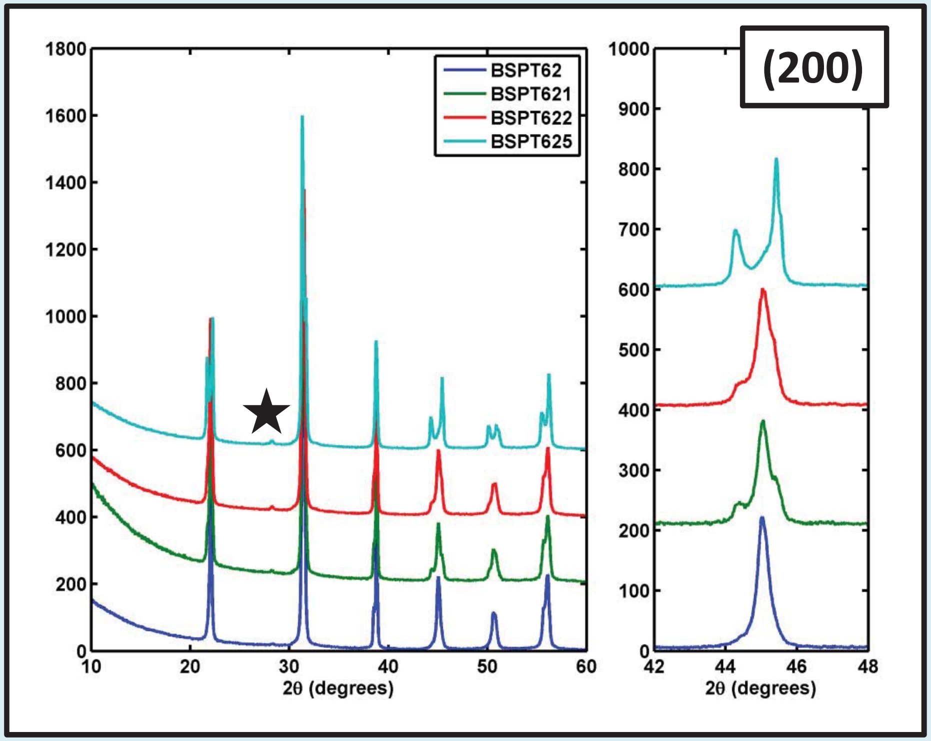
- Previous success with aliovalent Zr_{Sc} and compensated $Zn_{0.5}Zr_{0.5}$ on Sc
  - 2% Zr_{Sc} increases T_d by 20°C for 37BS – 63PT, with a decrease in T_c
- Compositions chosen from rhombohedral and tetragonal regions around MPB
- Aliovalent Zn_{Sc} chosen for high ferroelectric activity; hybridizes similiarly to Ti
- Conventional solid state processing
  - Calcine: 3hrs @ 750°C
  - Sinter: 1hr @ 1100°C

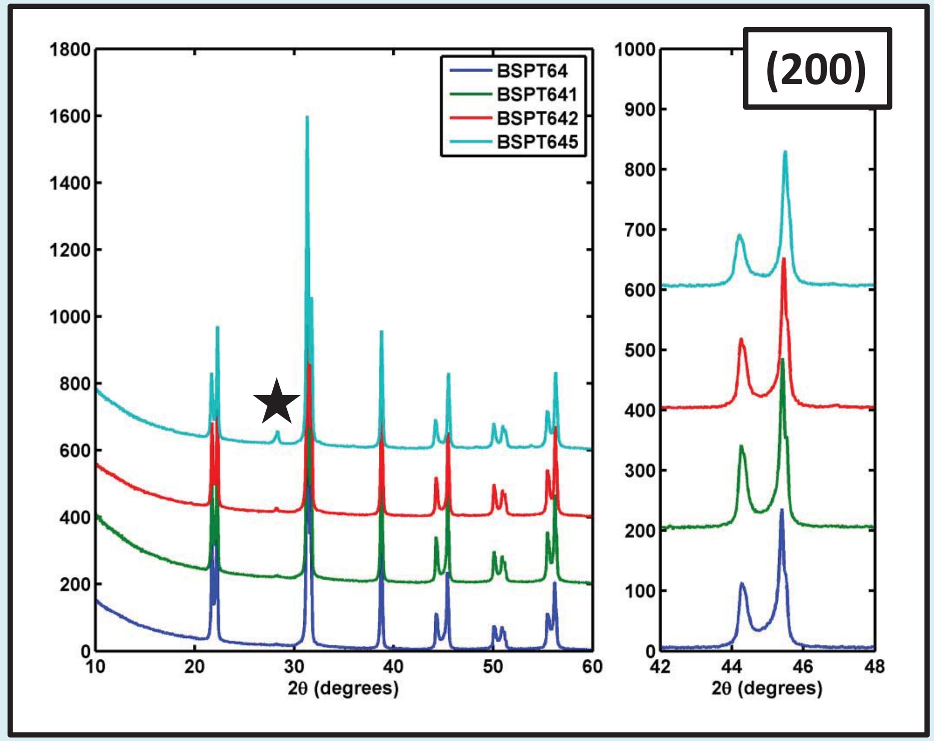


Nomenclature			
0% Zn	1% Zn	2% Zn	5% Zn
BSPT58	--	--	--
BSPT60	--	--	--
BSPT62	BSPT621	BSPT622	BSPT625
BSPT64	BSPT641	BSPT642	BSPT645
BSPT66	--	--	--

Zr_{Sc} doping – Sehirlioglu *et al,* J. Am. Cer. Soc., 2010
$Zn_{0.5}Zr_{0.5}$ doping – Kowalski *et al,* J. Am. Cer. Soc., 2013
Phase diagram – Eitel *et al,* J. Appl Phys., 2004

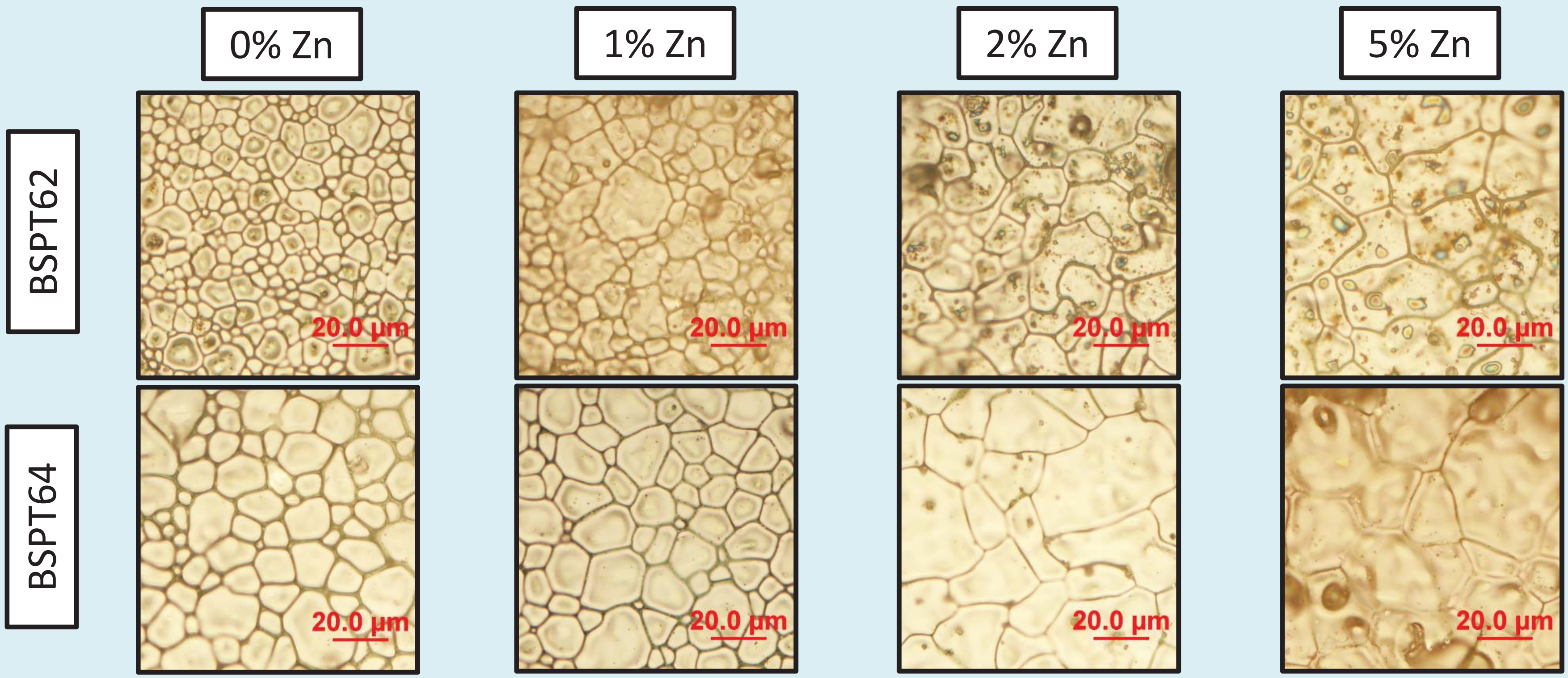
X-ray Diffraction Comparison





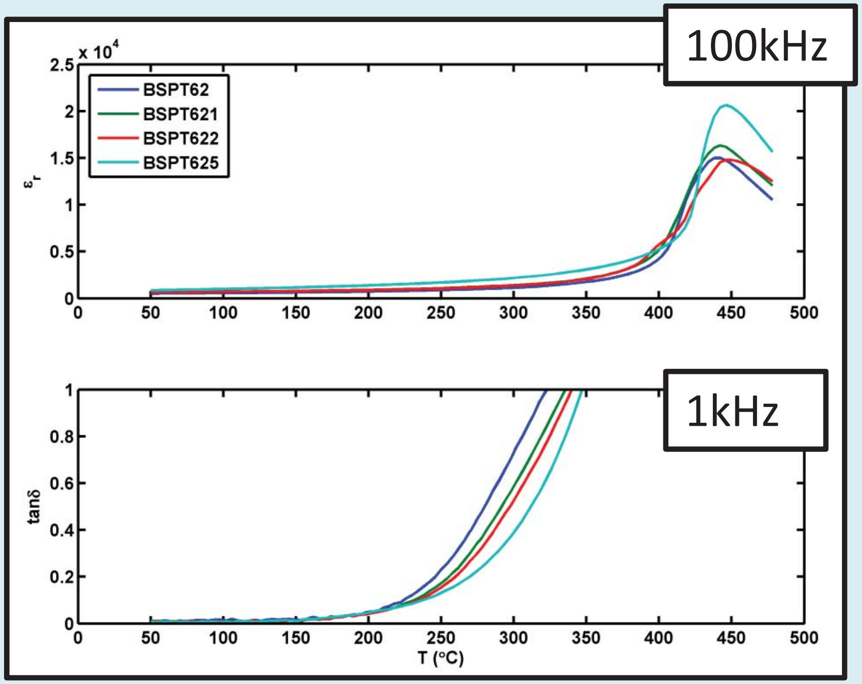
- BSPT62: Shifting rhombohedral/tetragonal ratio
- BSPT64: Increasing c/a ratio (1.011 to 1.013) with Zn addition
- ★: $Pb_xBi_{(1-x)}O$ phase

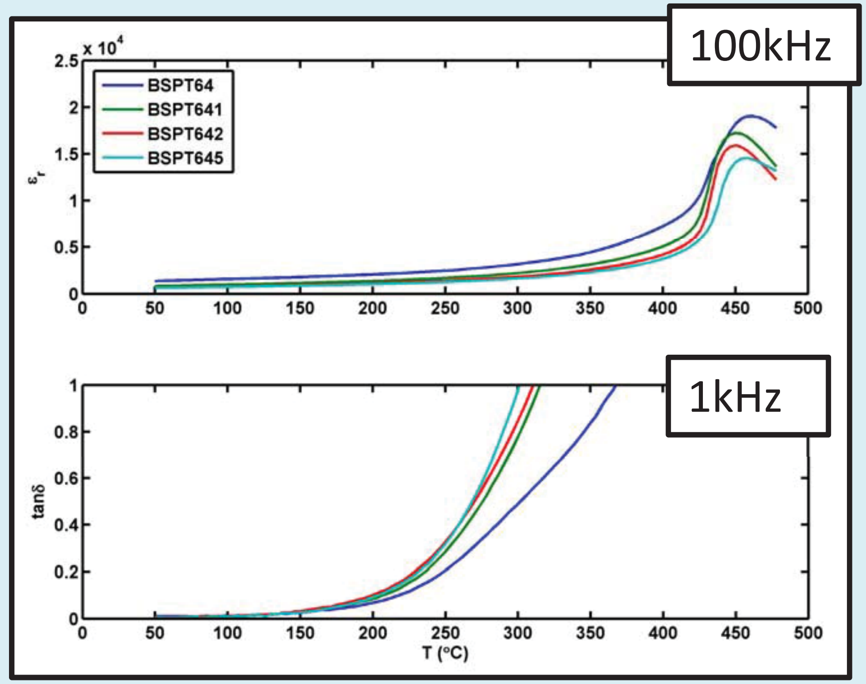
Optical Microscopy



- Density: > 96%; dense structures with low porosity
- Grain Size: tends to increase with Zn addition
- Size distribution: possible promotion of abnormal grain growth with Zn addition
- $Pb_xBi_{(1-x)}O$ observed in clusters at grain boundaries

Weak Field Measurements

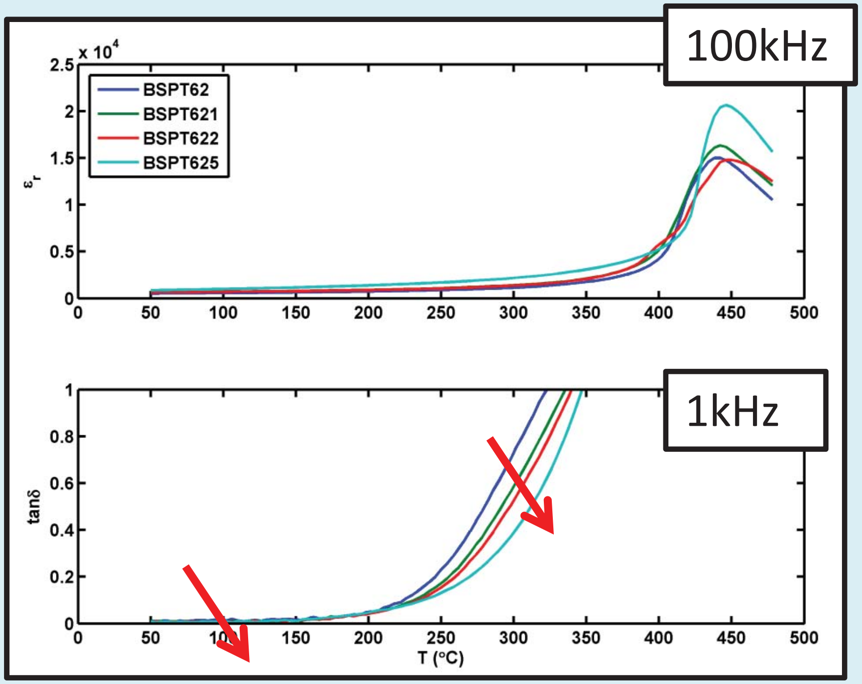


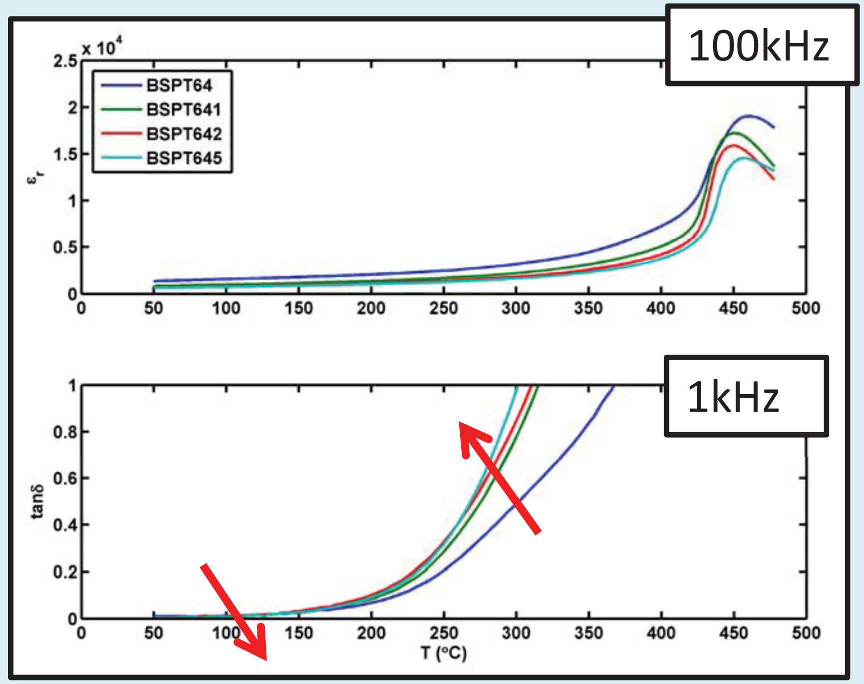


	0%	1%	2%	5%
ε_r 50°C	550	659	633	865
ε_r 300°C	1448	1686	1635	2686
tanδ 50°C	0.01	0.009	0.007	0.008
tanδ 300°C	0.730	0.586	0.526	0.389
ϵ” 50°C	5.5	5.93	4.43	6.92
ϵ” 300°C	1058	989	860	1046

	0%	1%	2%	5%
ε_r 50°C	1349	836	675	643
ε_r 300°C	3854	3071	2686	2408
tanδ 50°C	0.009	0.006	0.007	0.005
tanδ 300°C	0.49	0.782	0.844	0.952
ϵ” 50°C	12.14	5.02	4.73	3.22
ϵ” 300°C	1888	2402	2267	2292

Weak Field Measurements





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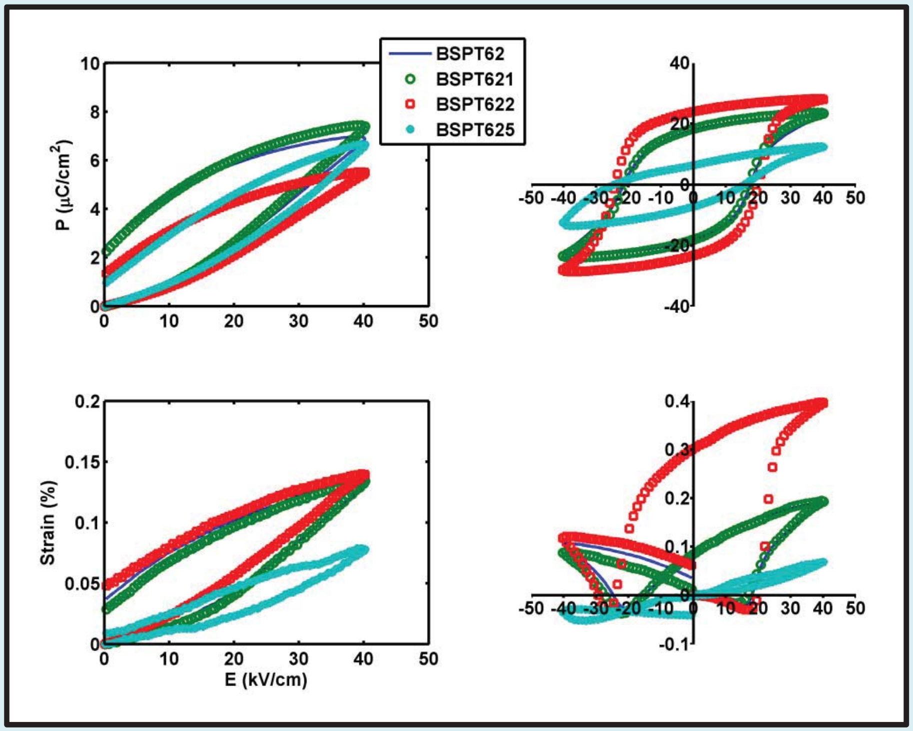
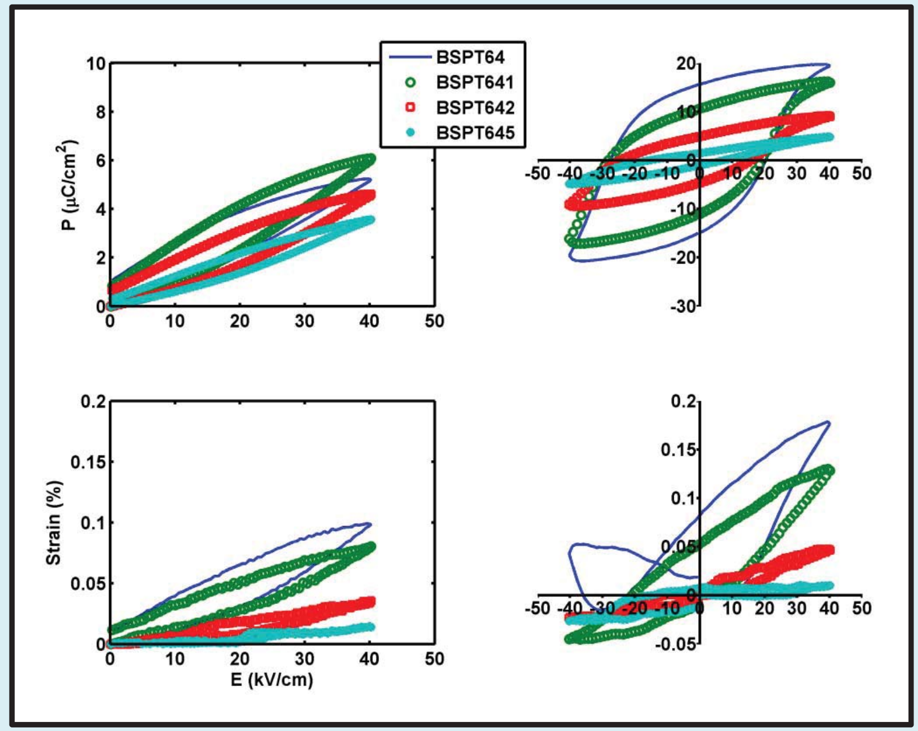
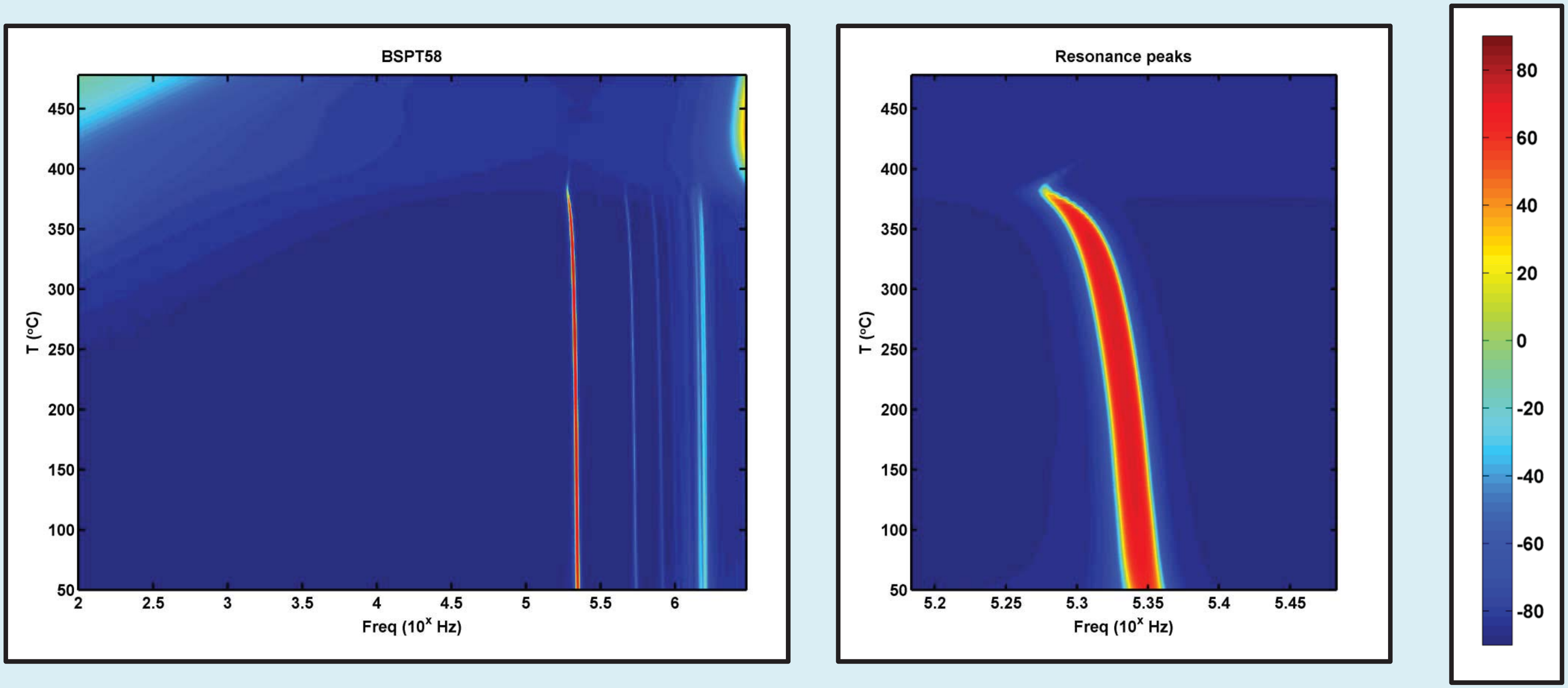
High Field Measurements





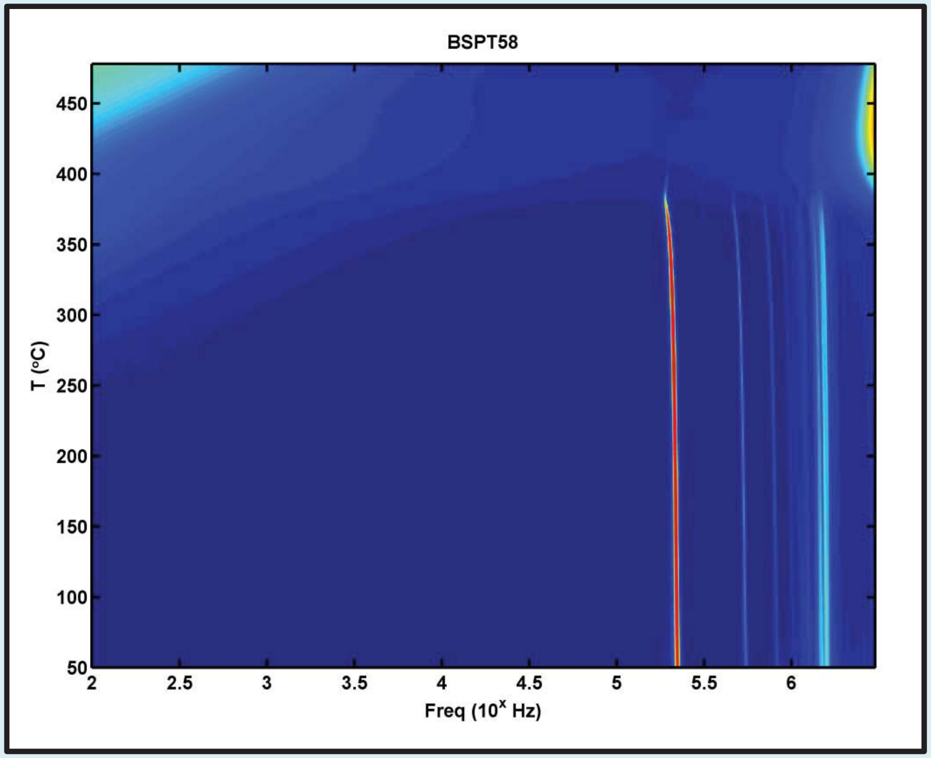
- Poled at 100°C under 40kV/cm for 30 min.
- BSPT62: Increased E_c, P_r with Zn addition
- Assymetric hysteresis
  - Doesn’t fully depole upon switching; Possible pinning from defects

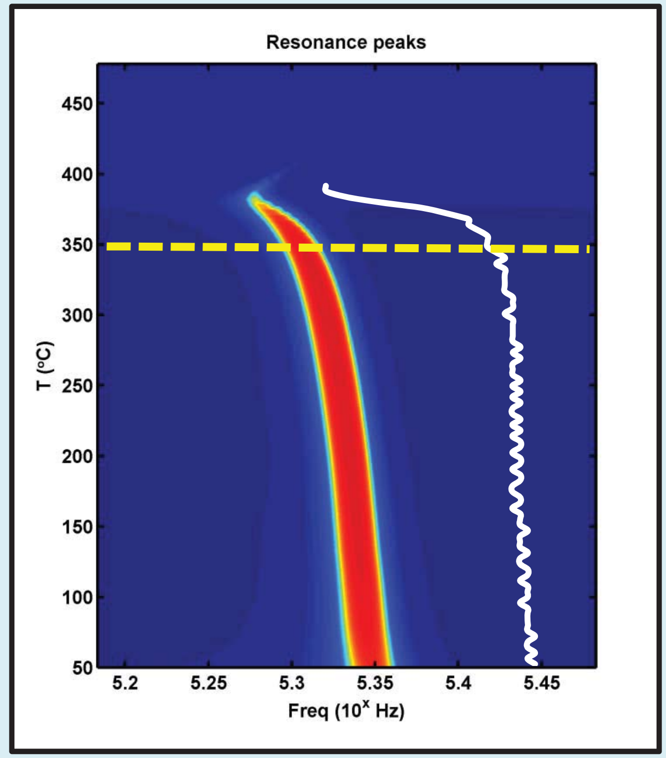
Phase angle (θ) – BSPT58

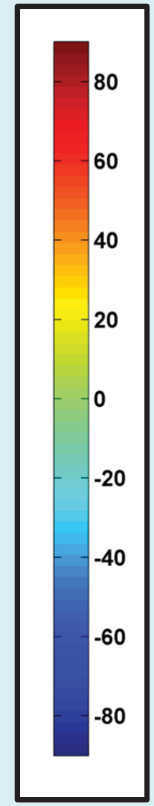


- Phase angle: 100Hz to 3MHz
- Width in phase angle peak related to coupling coefficients

Phase angle (θ) – BSPT58

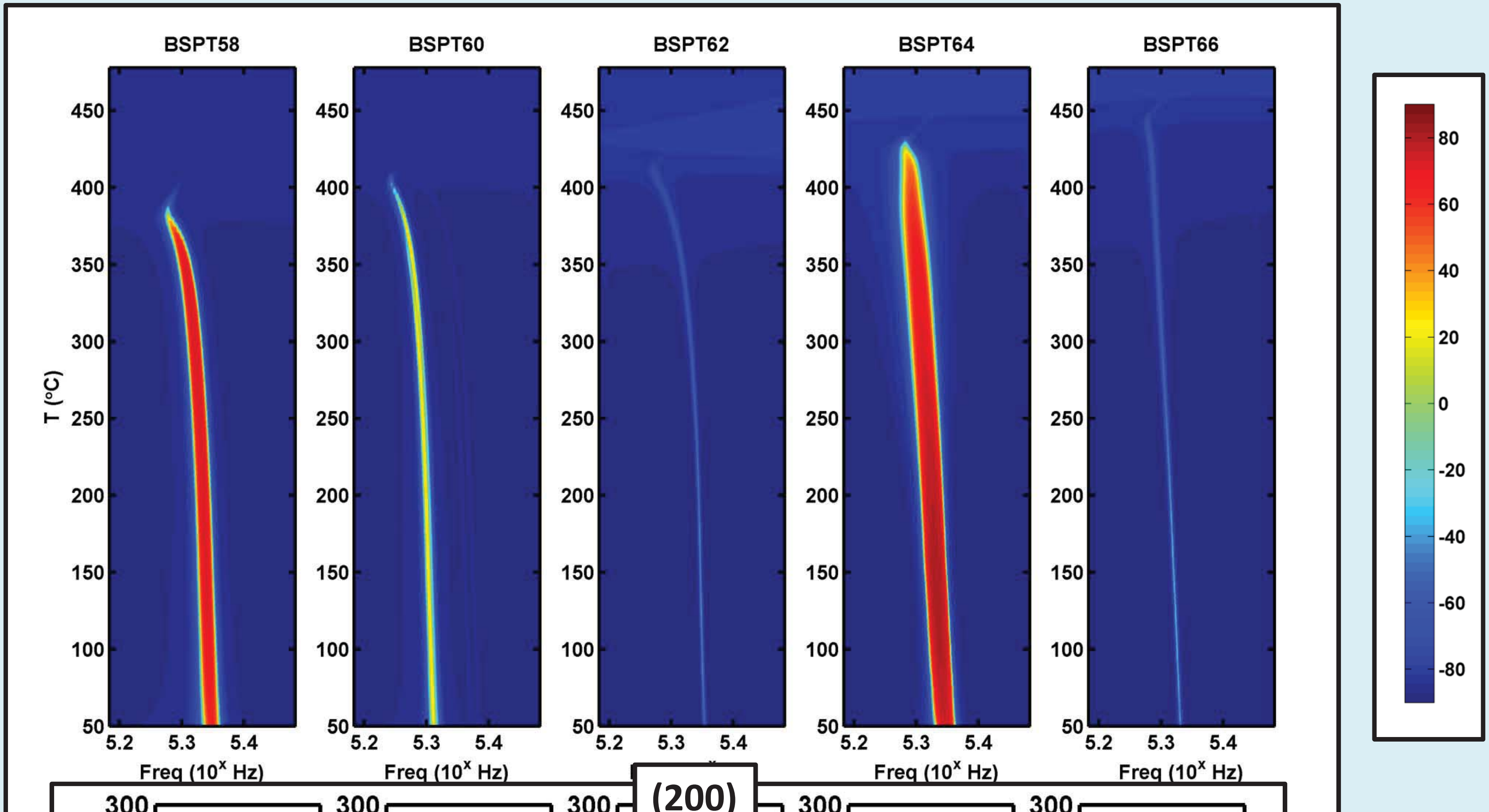


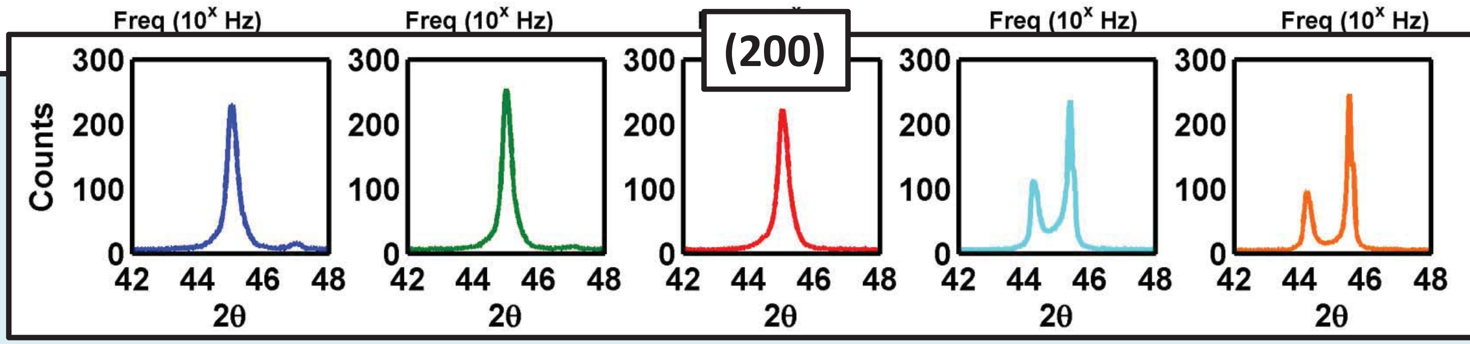




- Phase angle: 100Hz to 3MHz
- Width in phase angle peak related to coupling coefficients

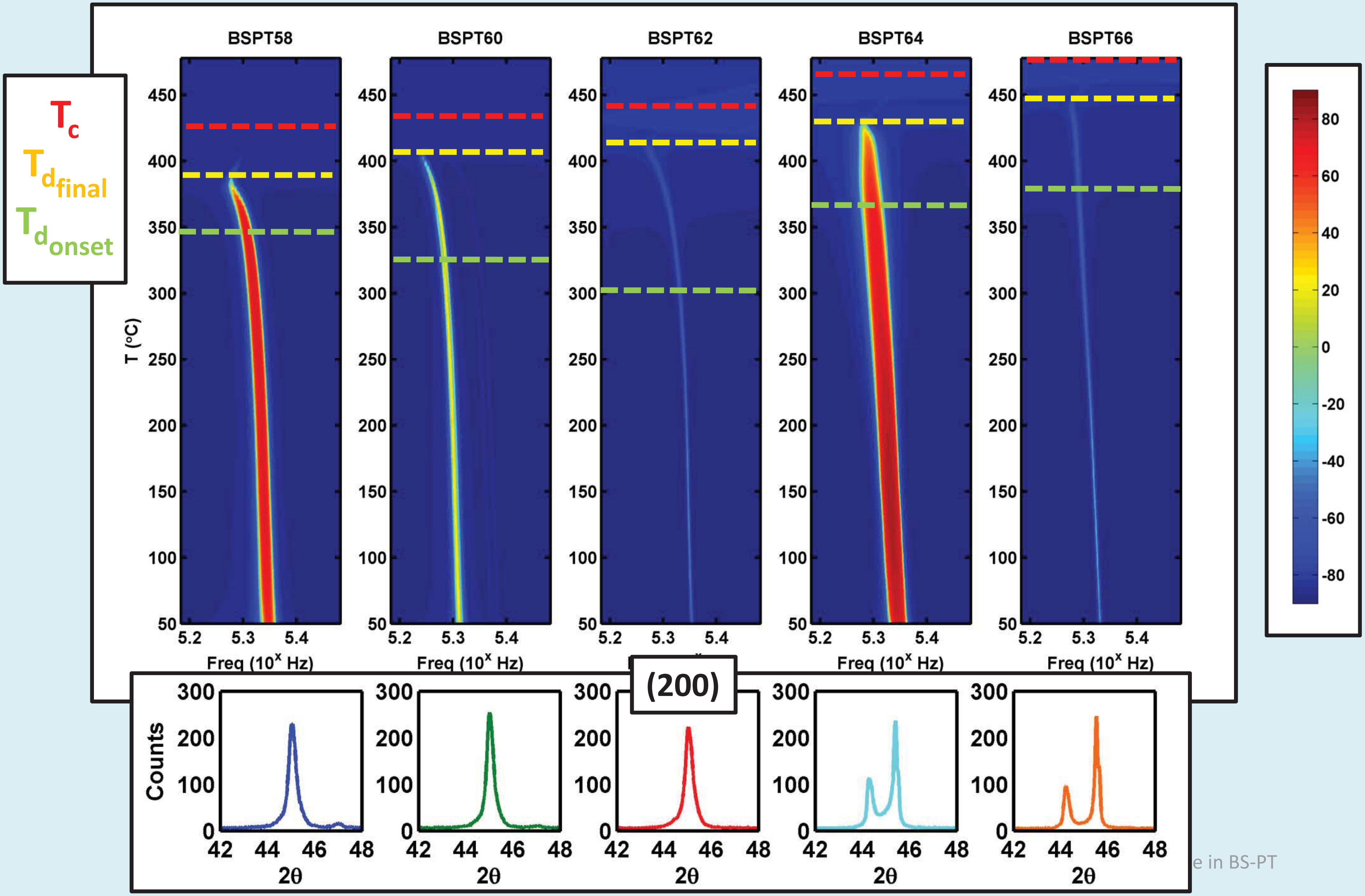
Phase angle (θ) – BSPT





e in BS-PT

Phase angle (θ) - Transitions



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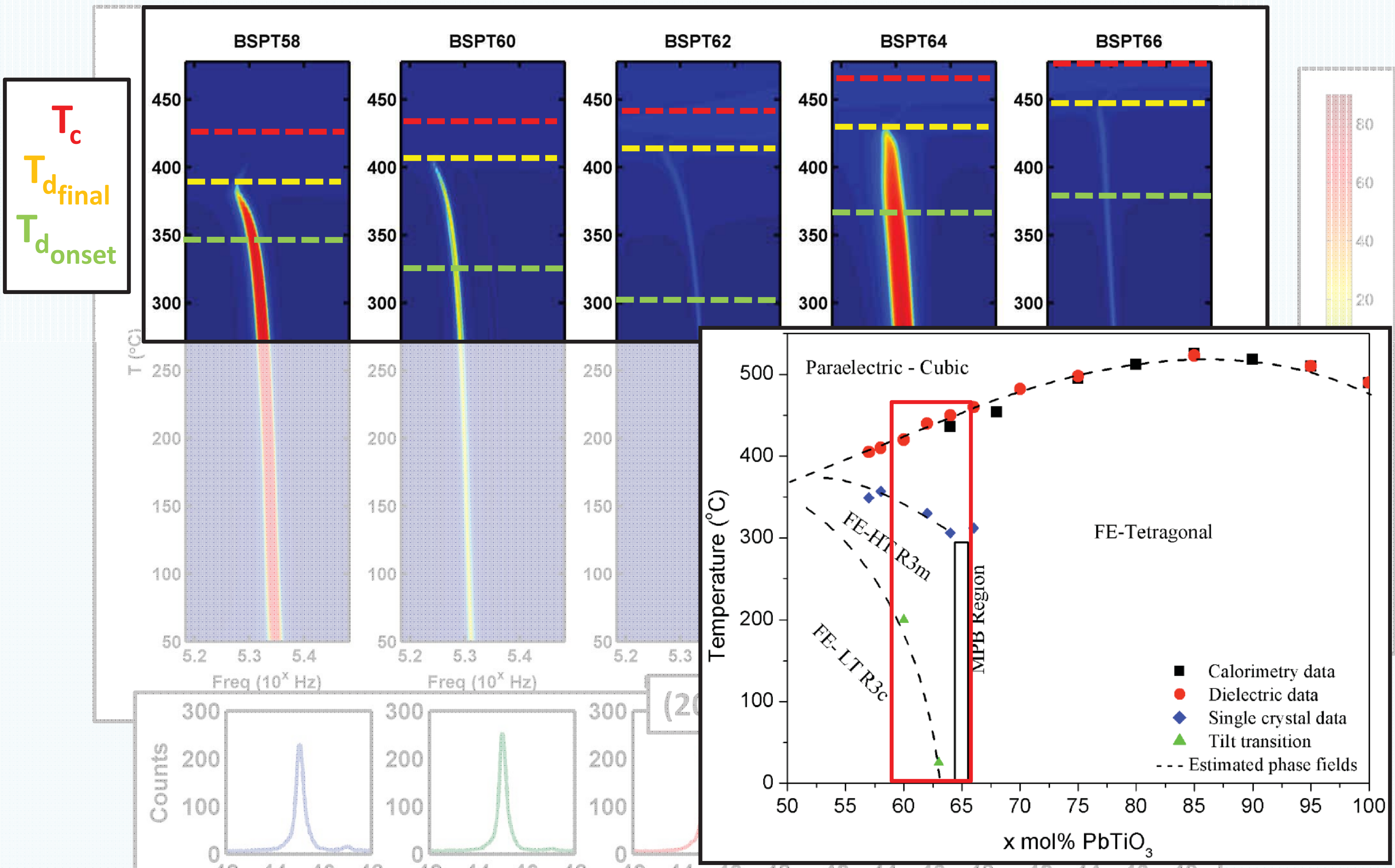
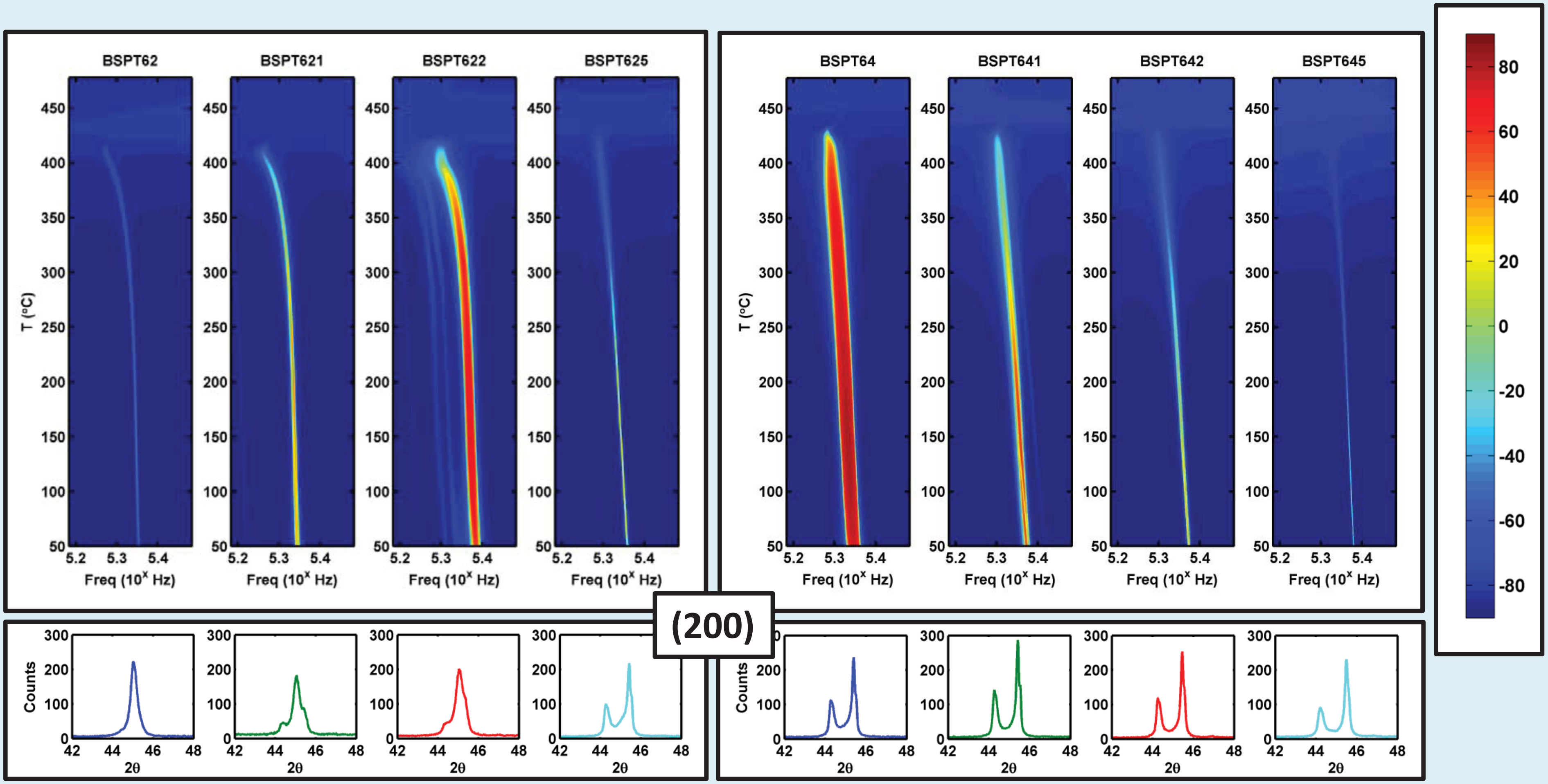


Eitel *et al*, J. Appl Phys., 2004

Phase angle (θ) - Comparison



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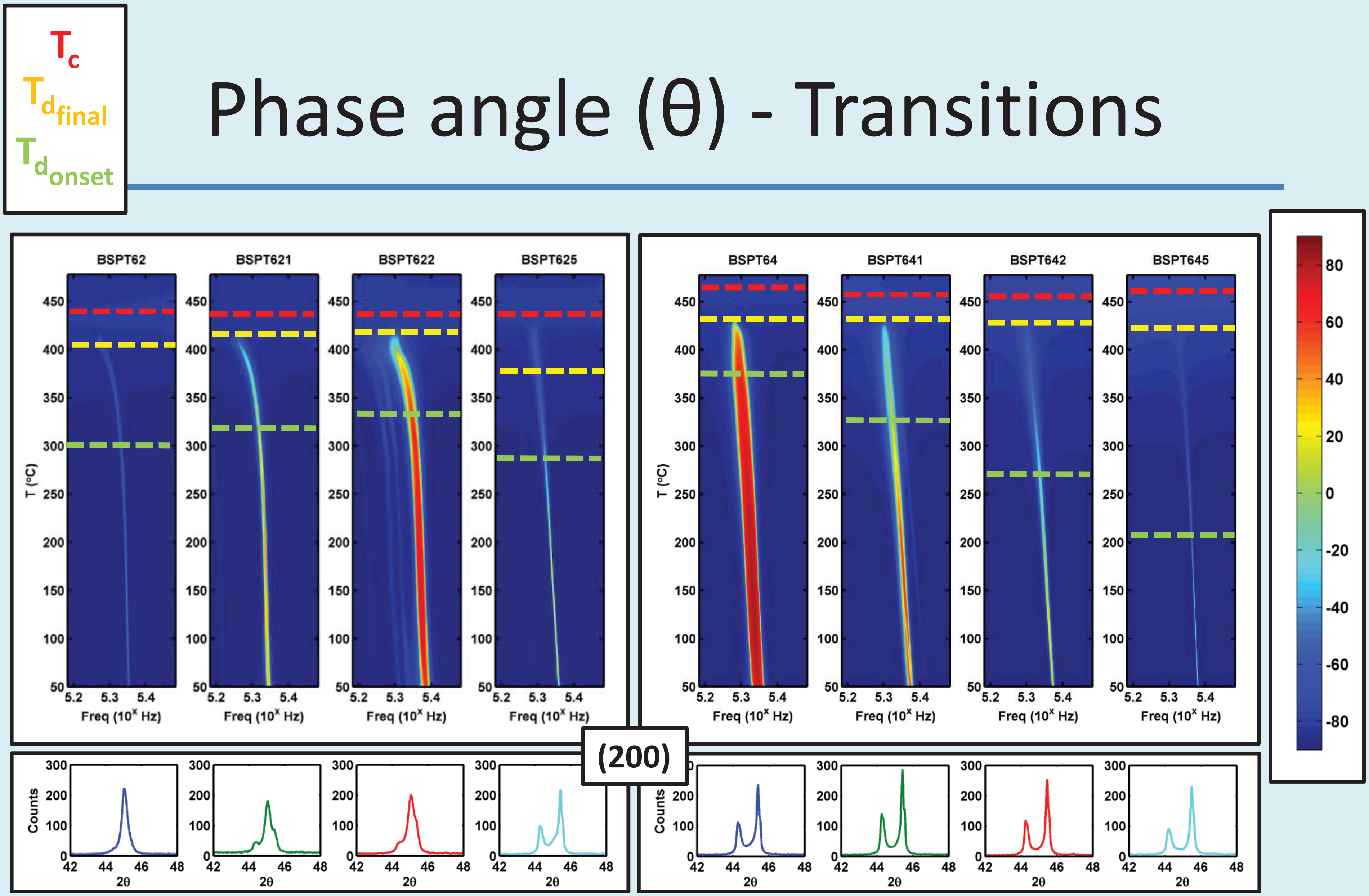
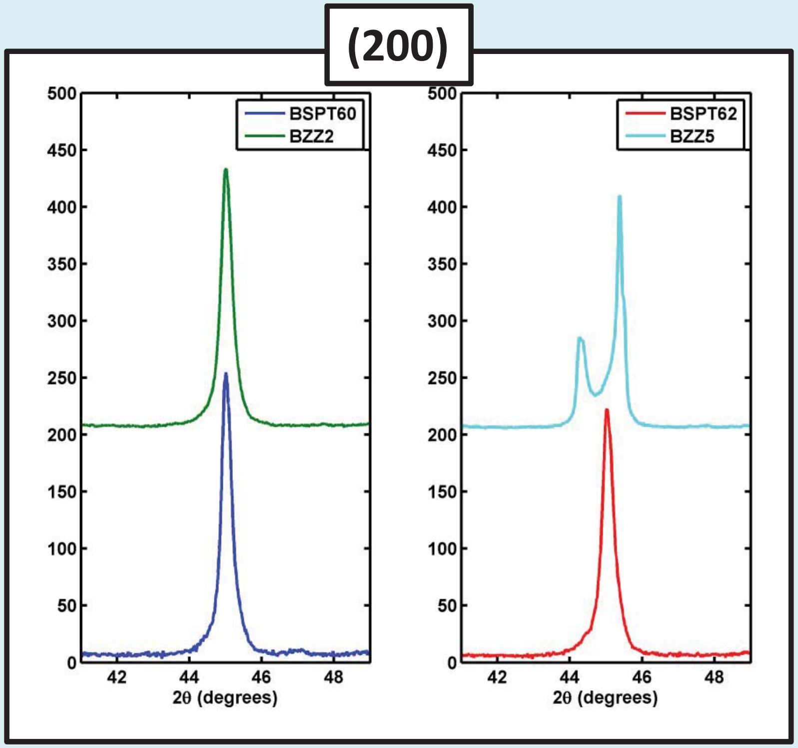
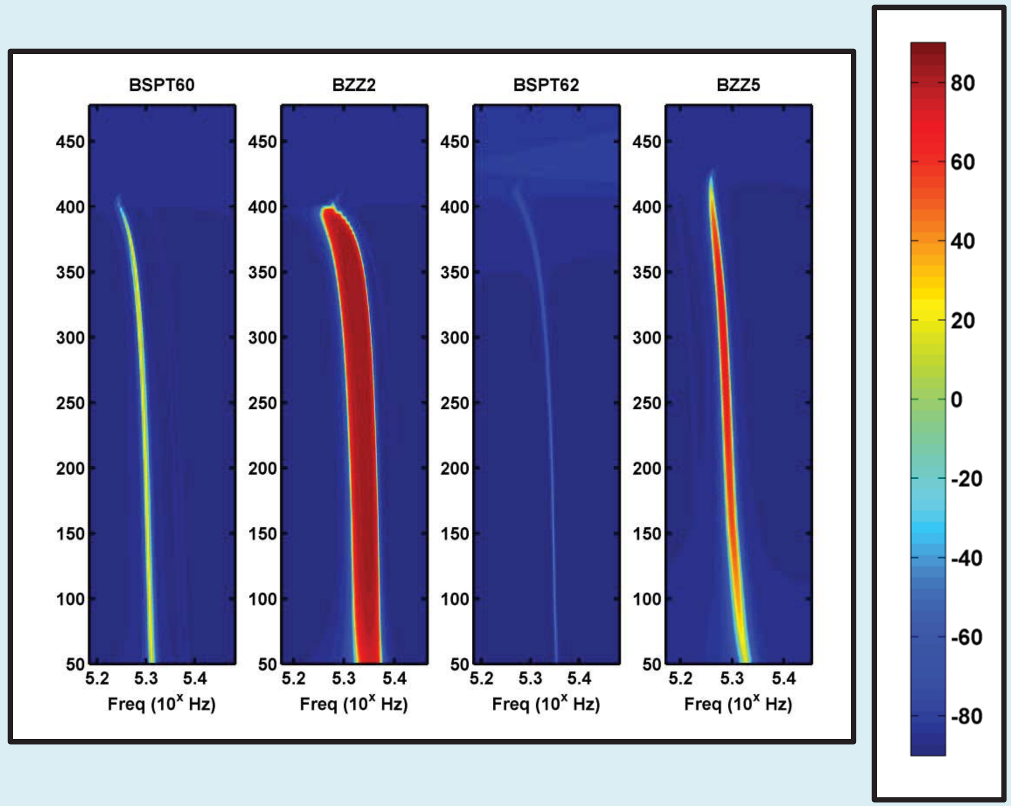


$Zn_{0.5}Zr_{0.5}$ for Sc



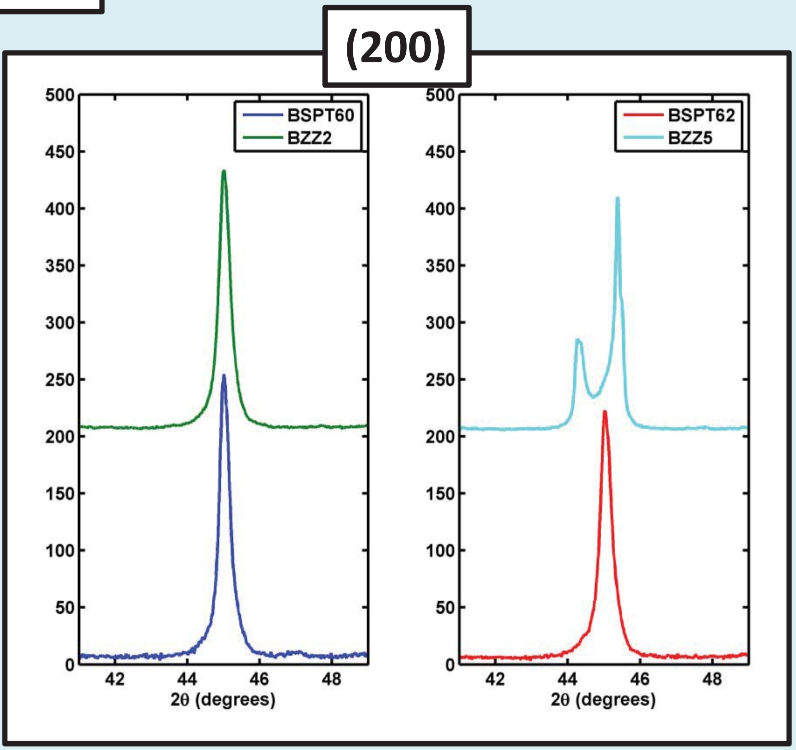


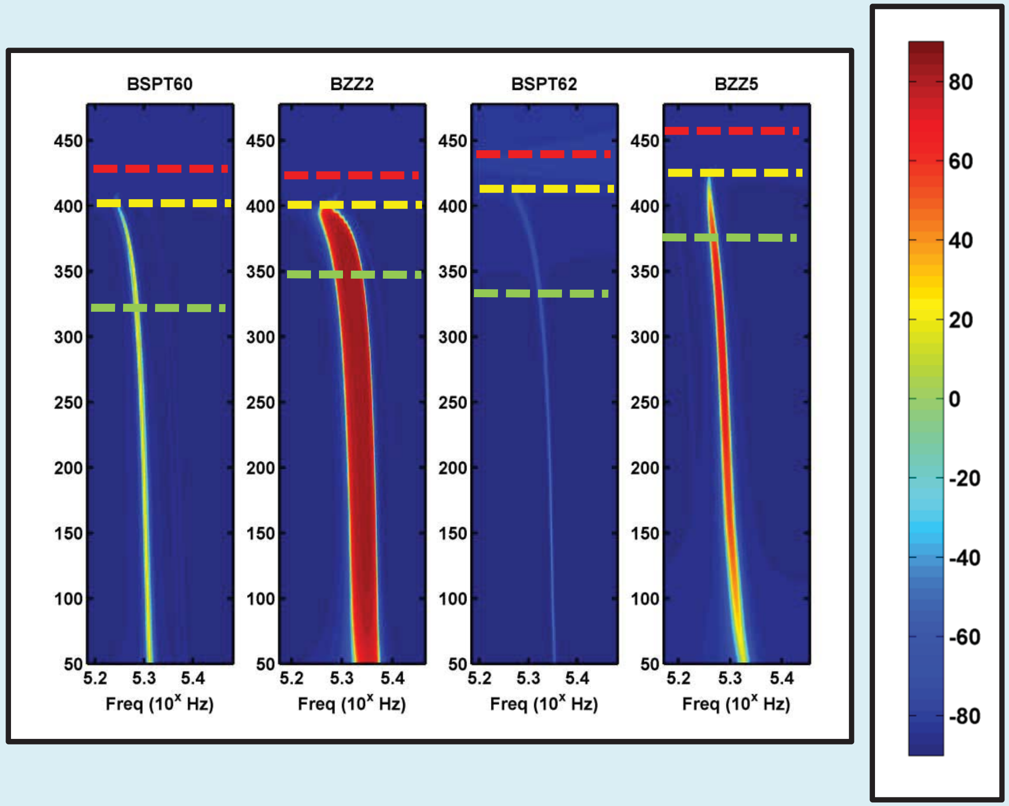
- BZZ2: 60$PbTiO_3$ – 40Bi[0.9375Sc,0.0625($Zn_{0.5}Zr_{0.5}$)]O_3
- BZZ5: 62.5$PbTiO_3$ – 37.5Bi[0.933Sc,0.066($Zn_{0.5}Zr_{0.5}$)]O_3

$Zn_{0.5}Zr_{0.5}$ doping – Kowalski *et al*, J. Am. Cer. Soc., 2013

T_c
$T_{d_{final}}$
$T_{d_{onset}}$

$Zn_{0.5}Zr_{0.5}$ for Sc





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$Zn_{0.5}Zr_{0.5}$ doping – Kowalski *et al,* J. Am. Cer. Soc., 2013

Conclusions

- We looked at the effects of Zn_{Sc} on T_d and relevant properties
- Zn_{Sc} increases $T_{d,onset}$ for BSPT62 compositions while also slightly enhancing electromechanical properties
- Structure specific tanδ behavior for Zn_{Sc}
- $Zn_{0.5}Zr_{0.5}$ increases electromechanical properties and $T_{d,onset}$
- Combine with other aliovalent dopants to tailor properties further

Would like to thank:

Fred Dynys, Tom Sabo – NASA GRC

Jon Mackey – University of Akron

Funded by:

NASA GSRP Fellowship: NNX11AL17H

AFOSR: FA9550-0601-1-0260