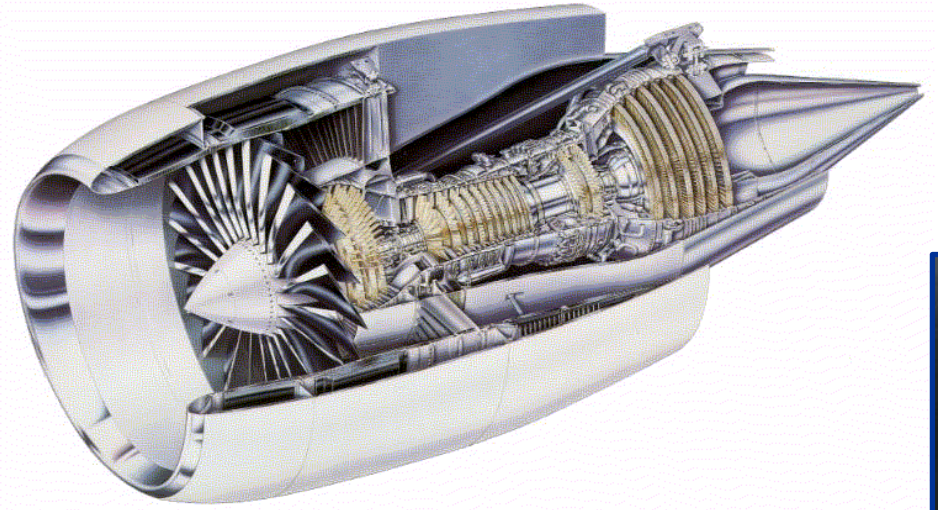
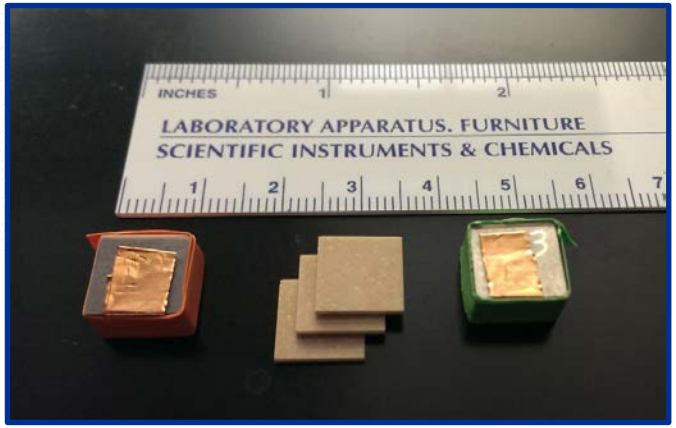
High Temperature Fuel Modulation for Improved Engine Performance





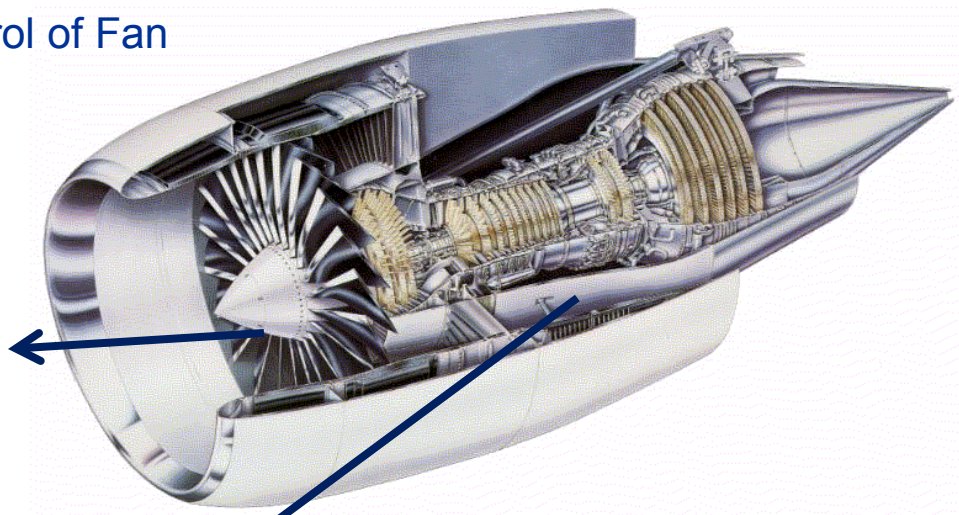
Alp Sehirlioglu

Department of Materials Science and Engineering

Case Western Reserve University

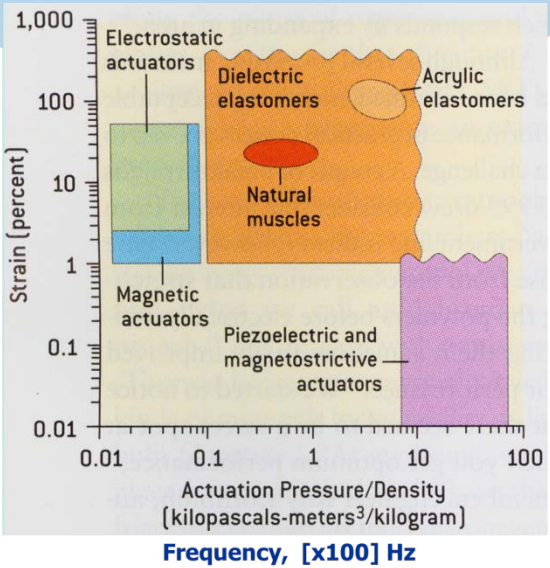
Green Engines

Active and Passive Vibration Control of Fan Blade Using Piezoceramics



Advantages:

- Fast response time
- Generate large forces
- No gears or rotating shafts, no wear and tear.



Fuel modulation:
– Increased engine efficiency
– Decreased NO_x gases

Coolant modulation:
Equivalent power can be obtained with a lower inlet temperature, thus less fuel

Kim et al., Proc Instn Mech Engrs 211 Part A, 443 (1997).

Noise minimization:
Fan, turbine, compressor, exhaust, combustor.

Atomizier:
Spray atomization is very important to reduce the fuel/air mixing time

Application:
Develop new materials and concepts that enable higher turbine engine operating temperatures

Benefits:

- ***Increased turbine engine operating temperate can dramatically increase fuel efficiency & reduce emissions***
- ***Current DOD study shows only reasonable way to increase engine temperature is by advanced materials***
- ***2001 Stanford study shows a $1B/year fuel savings if engines run 1 degree C hotter***

Properties that matter

- Piezoelectric coefficients (d_{ijk})

$$D_i = d_{ijk}\sigma_{jk} \qquad \varepsilon_{jk} = d_{ijk}E_i$$

- Electromechanical coupling coefficients (k_{33}, k_{31}, k_p, k_t)

$$k^2 = \frac{E \quad l \quad e \; Ec \quad m \; r}{M \quad e \quad cE \; h \; n}$$

= Energy conversion efficiency

- AC and DC resistivity

Material has to be insulating at high temperatures (DC)
Material should not heat up at high frequency loading (AC)

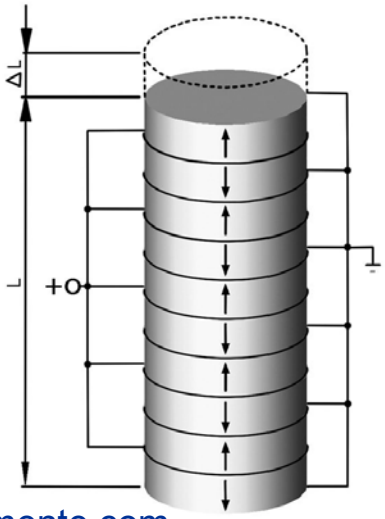
- Coercive field (E_c)

Electrical hardness, ability to apply higher negative bias for larger stroke, better ability to handle mechanical load

Fuel modulation

- Lean combustion: high-performance operation (increase efficiency, reduced emissions), lower stability (thermoacoustic instabilities).
- Large pressure oscillations due to instability: damage equipment, reduce efficiency, increase emissions, and blow out the flame. High-bandwidth fuel modulation for controlling combustion instabilities.
- Active combustion control require compact, robust, low-cost actuators that are capable of high-frequency operation.
- Piezoelectric and magnetostrictive materials, operation frequencies exceeding 1 kHz
- Magnetostrictive actuators are larger, less technologically advanced, achieve narrower bandwidth, higher cost.
- Piezoelectric actuators: large forces, high frequency.
- Stacks: To amplify the strain (0.1% per layer), decrease operating voltage.
- Other strain amplification (levers, bimorphs etc.), at the expense of force and more complex
- Pressure bias: Operation in compressive range.

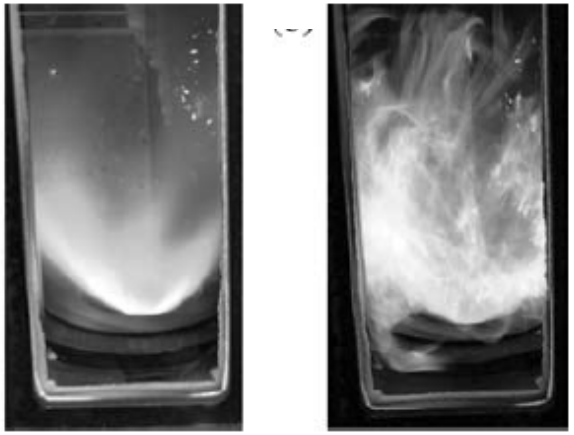
Piezomechanik GmbH



http://www.physikinstrumente.com

The fundamental peak of the combustion instability was reduced by 30 dB, and the broadband sound pressure levels inside the combustor were reduced by 12 dB.

Flame

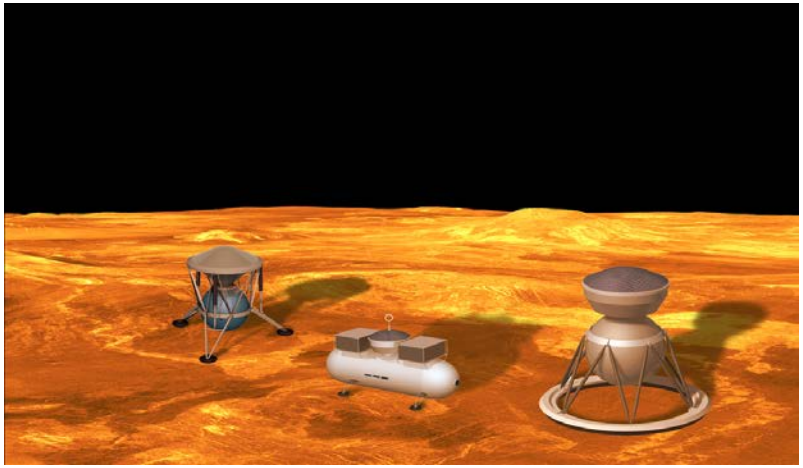


Stable Region Unstable Region

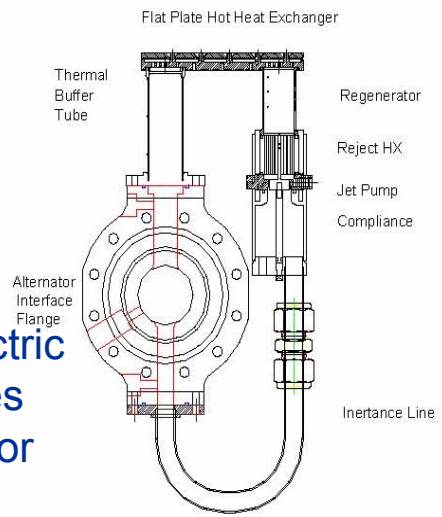
Schiller et al., J. Int. Mat. Sys. Str. 17, 403 (2006).

Other applications

NASA space: (Rodger Dyson)



Piezoelectric replaces alternator



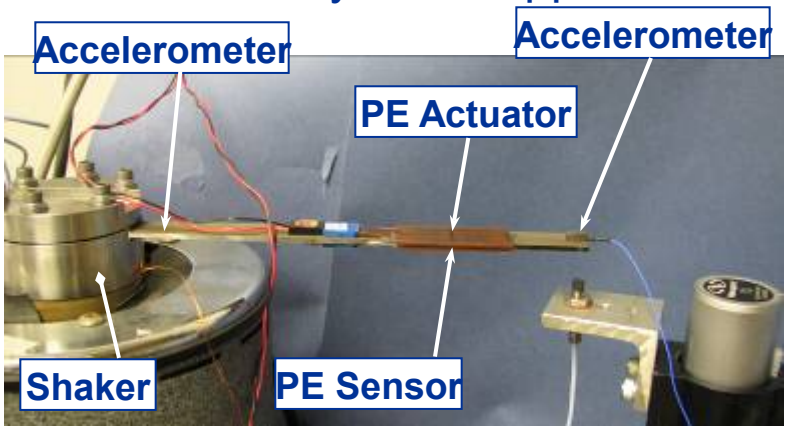
Gas drilling:

Drilling
Acoustic borehole logging
Ultrasonic flow meters,

Challenges:
Increased pressures
Increased temperatures
resulting from increased depth.

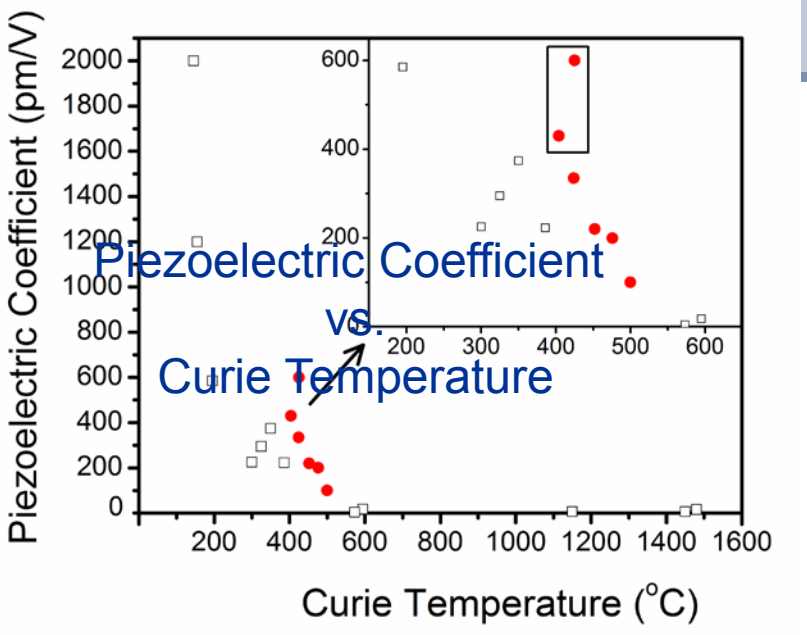
Smart Piezoelectric Damping Technology:

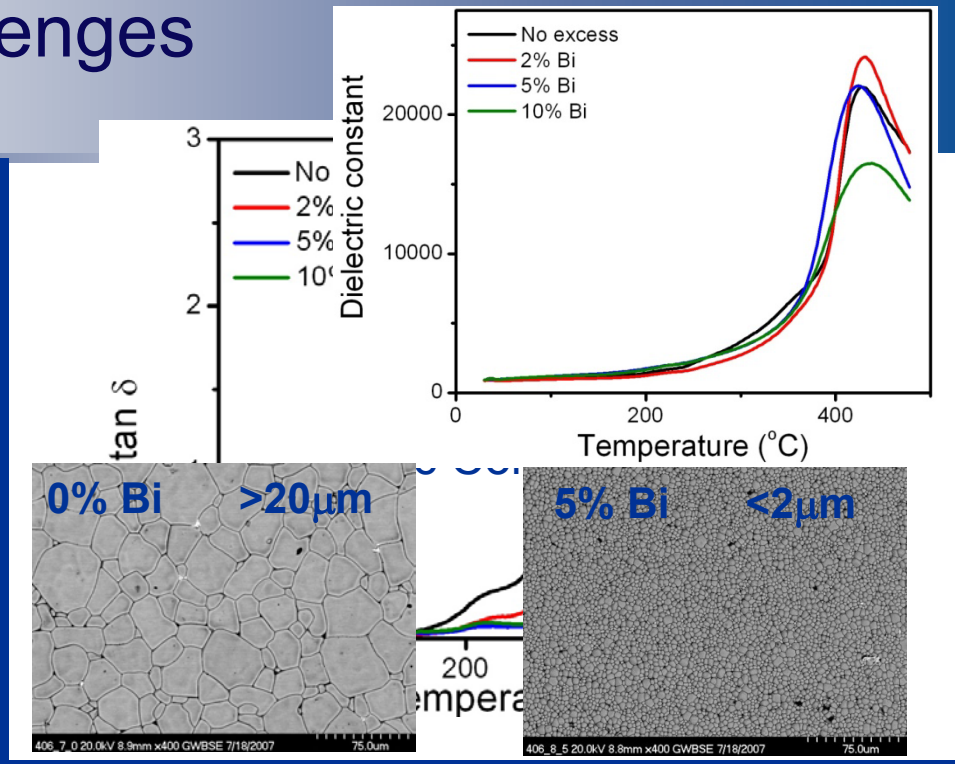
Piezoelectric damping system for high temperature turbomachinery blade applications

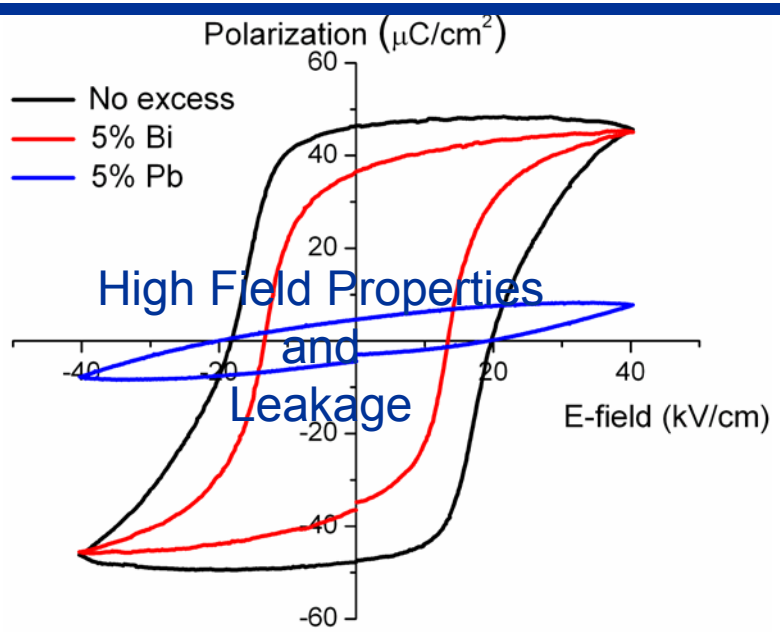


In collaboration with Kirsten Duffy / GRC

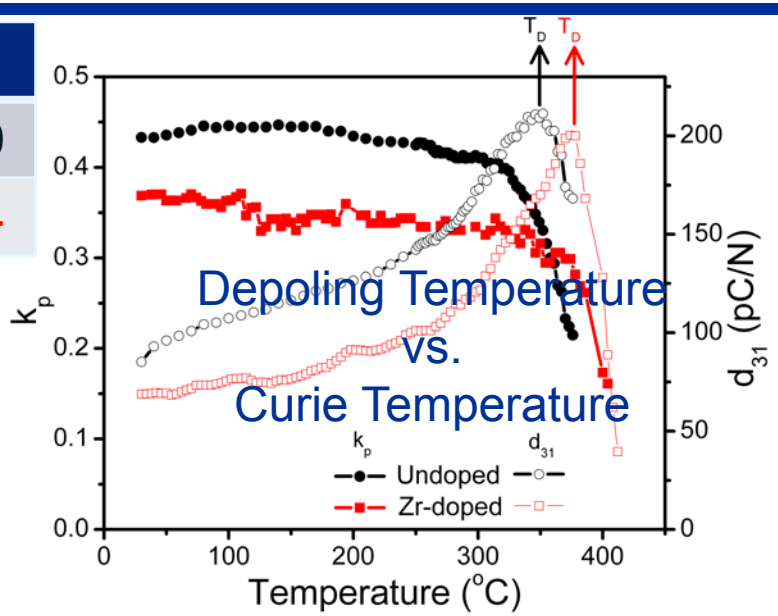
Challenges



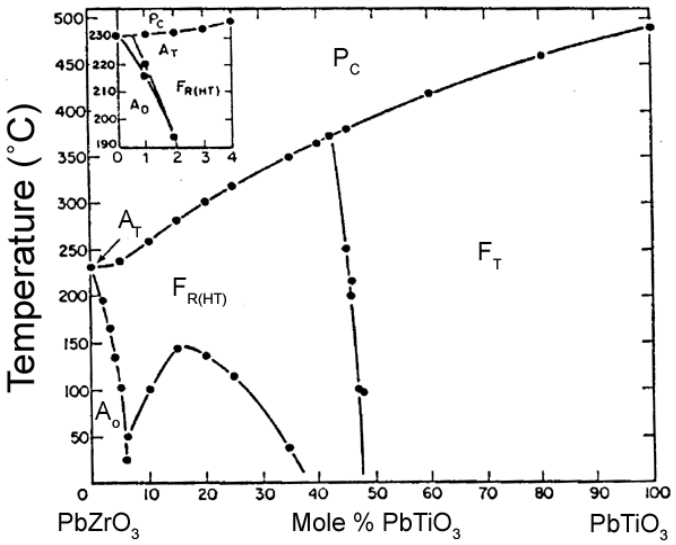




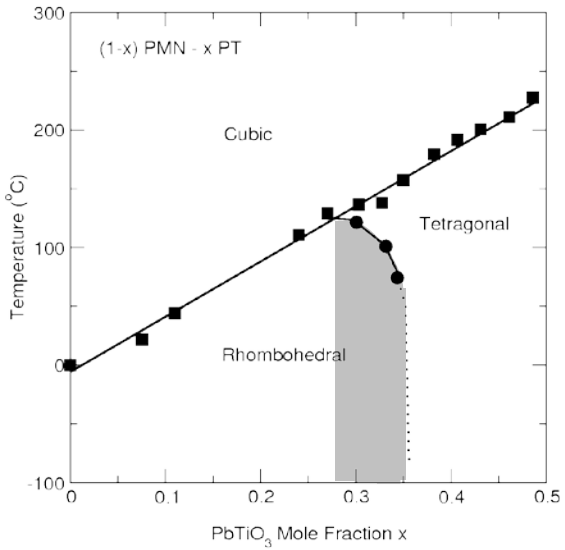
T_C
430
404



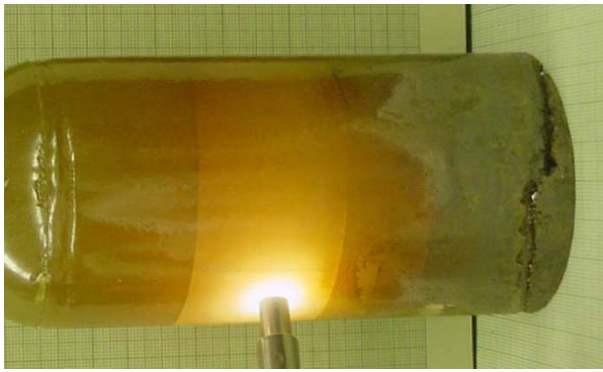
Piezoelectric Ceramics



B. Jaffe, W. R. Cook and H. Jaffe, Piezoelectric Ceramics, Academic Press, New York, 1971.

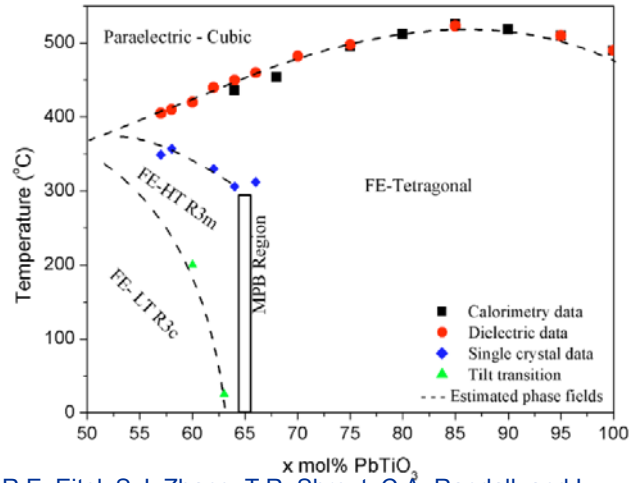


Shrout T., Zung P. C., Namchul K., Markgraf S. Ferroelectrics Letters **12**: 63-69, 1990.

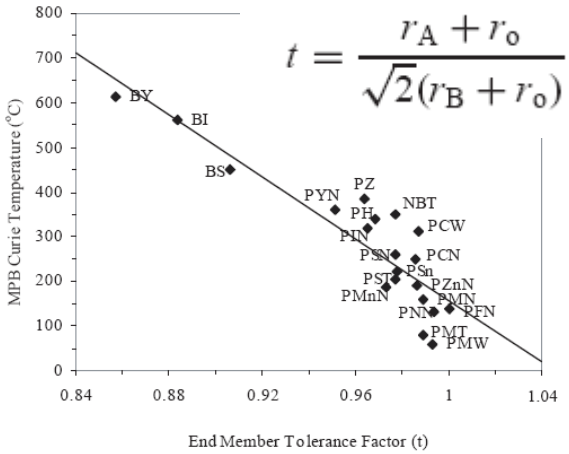


H.C. Materials Corp.

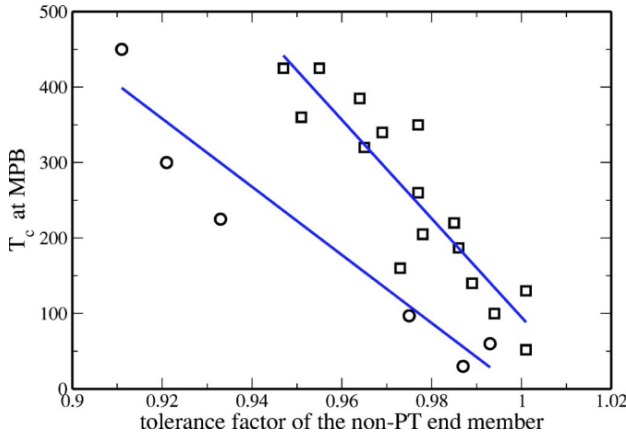
A. Sehirlioglu, P.D. Han, and D.A. Payne, J. Appl. Phys. **99**, 064101 (2006).



R.E. Eitel, S.J. Zhang, T.R. Shrout, C.A. Randall, and I. Levin, J. Appl. Phys., 96 [5] 2828–31 (2004).



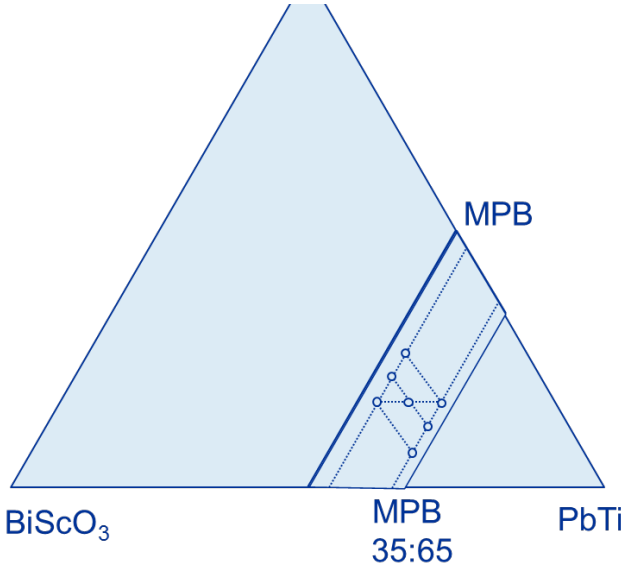
R.E.Eitel, C.A.Randall, T.R. Shrout, P.W. Rehrig, W.Hackenberger and S.E. Park, Jpn. J. Appl. Phys., 40 Pt.1 [10] 5999 (2001).

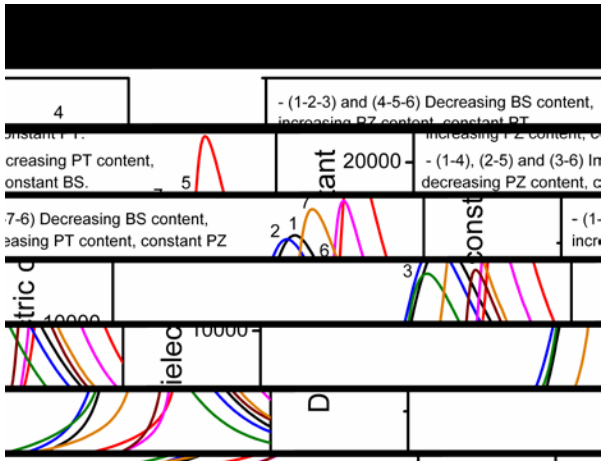


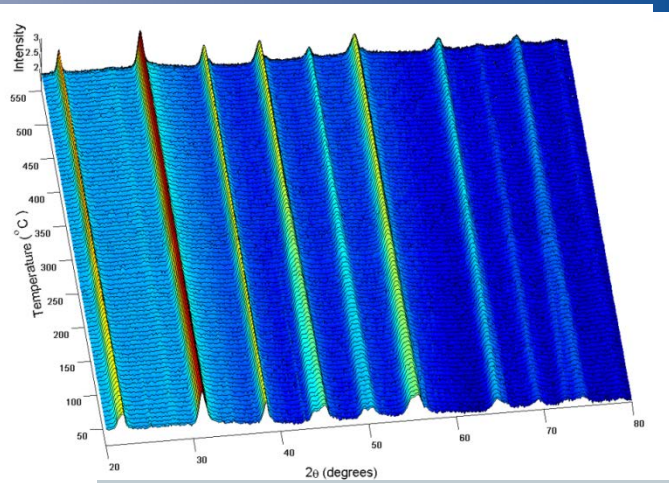
I. Grinberg, M. Suchomel, P. Davies, and A. Rappe, J. Appl. Phys., **98** 094111, (2005).

Ternary Phase Diagram

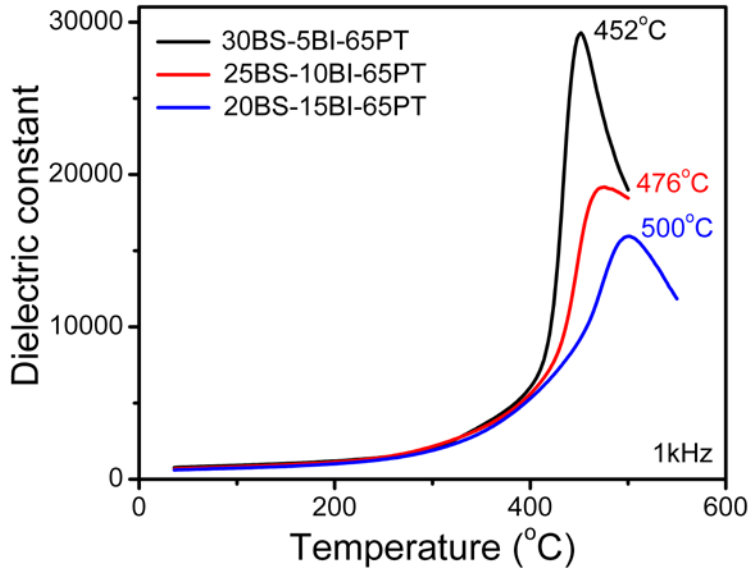
ABO_3=$BiInO_3$, $BiYbO_3$, $Bi(Zn,Zr)O_3$, $Bi(Zn,Ti)O_3$

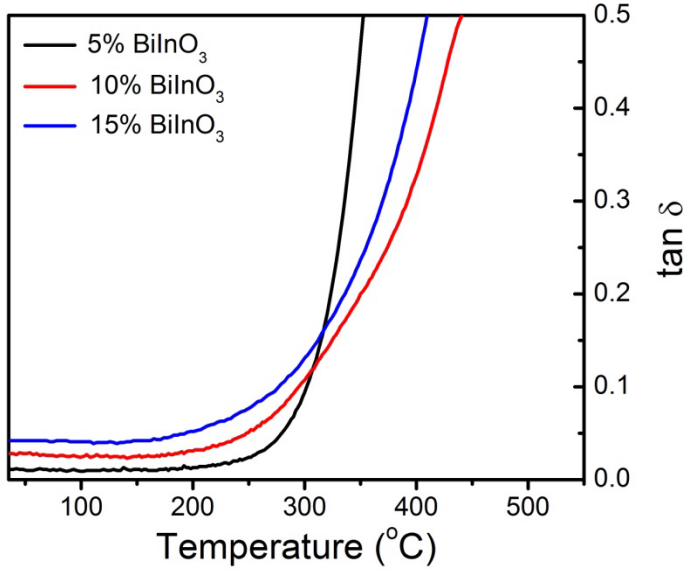




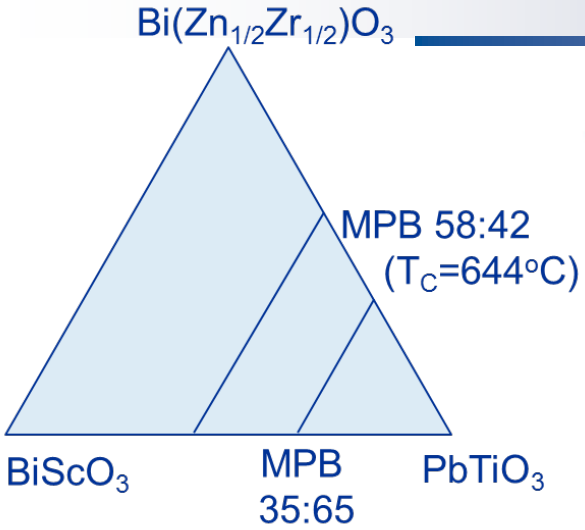


Jacob Jones, Materials Science and Engineering, University of Florida



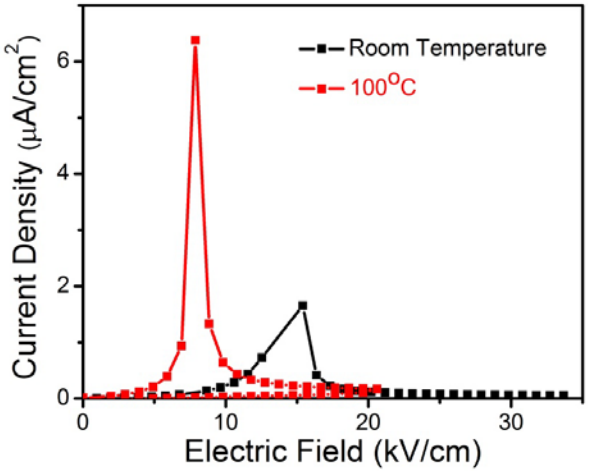


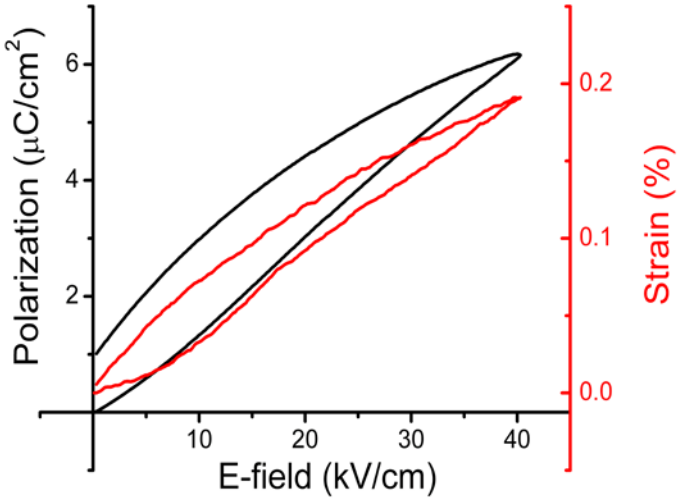
BS-PT-BZZ near MPB

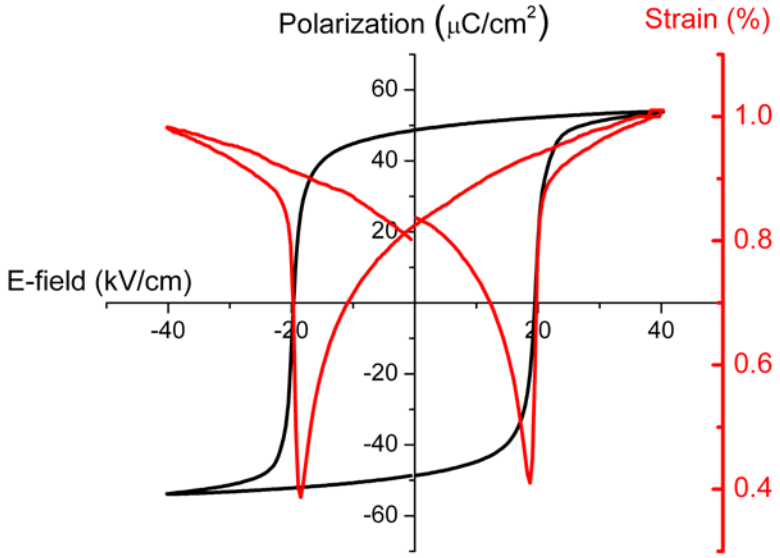


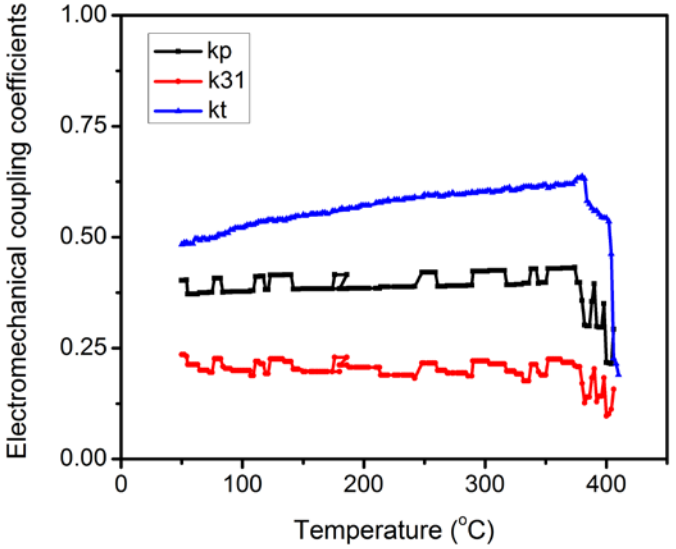
r_{Sc} = 0.745, t = 0.910

$r_{Zn,Zr}$ = 0.730, t = 0.916

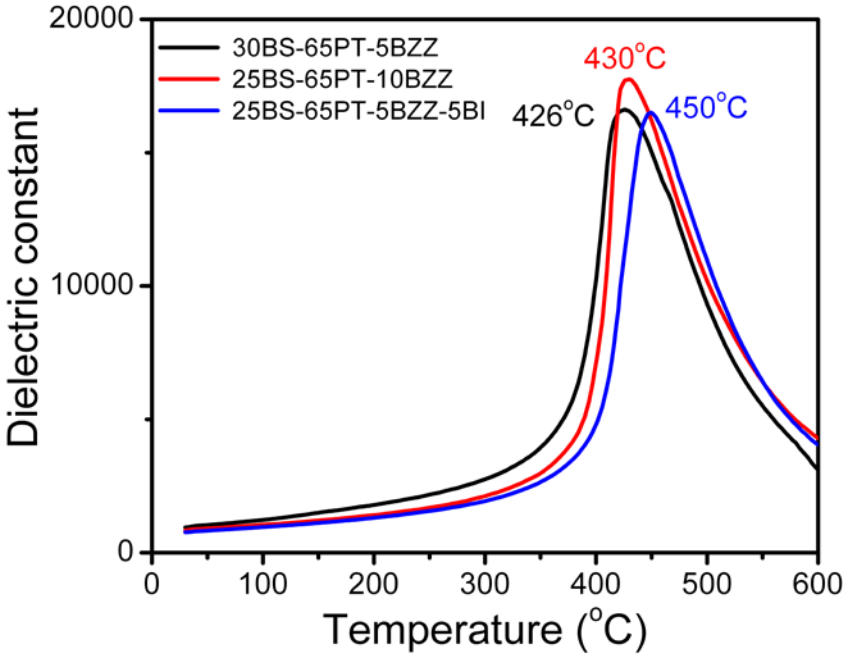


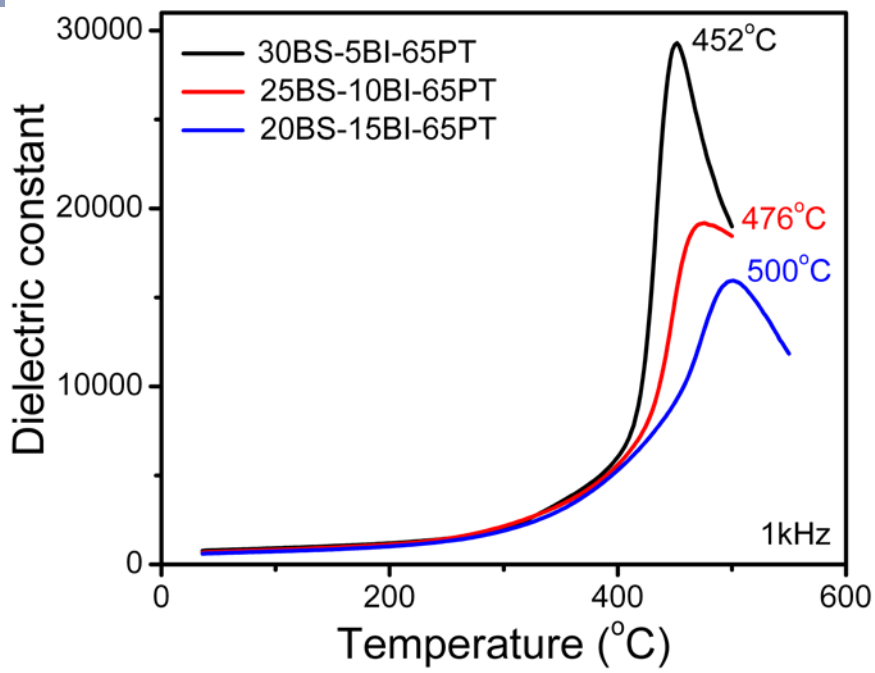


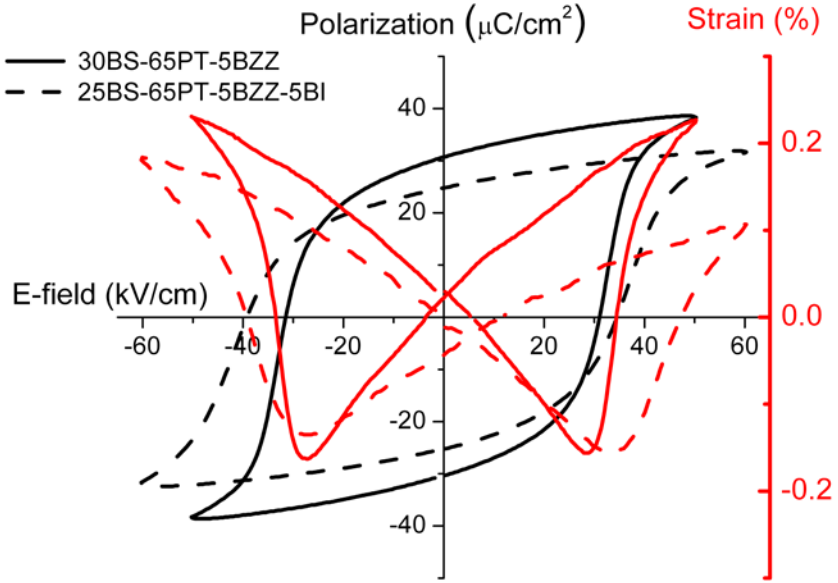


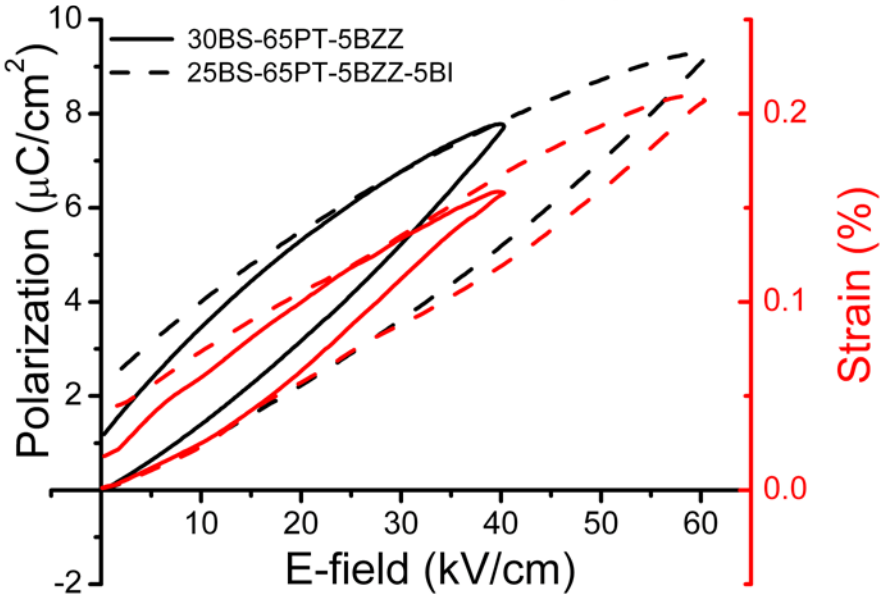


BS-PT-BZZ-BI


30BS-65PT-5BZZ
25BS-65PT-10BZZ
25BS-65PT-5BZZ-5BI
426°C
430°C
450°C
Dielectric constant
Temperature (°C)

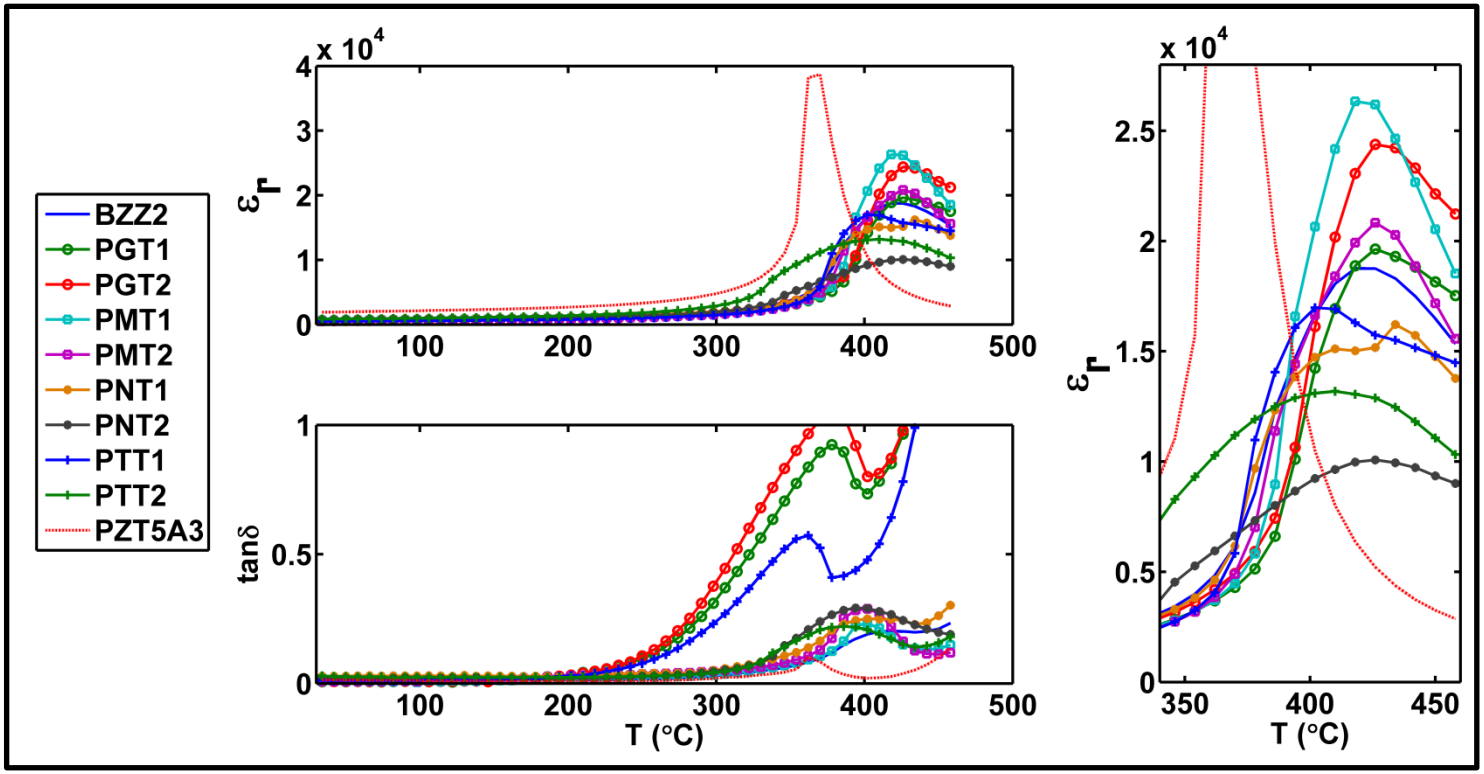

30BS-5BI-65PT
25BS-10BI-65PT
20BS-15BI-65PT
452°C
476°C
500°C
1kHz
Dielectric constant
Temperature (°C)


Polarization (μC/cm²)
Strain (%)
30BS-65PT-5BZZ
25BS-65PT-5BZZ-5BI
E-field (kV/cm)


30BS-65PT-5BZZ
25BS-65PT-5BZZ-5BI
Polarization (μC/cm²)
Strain (%)
E-field (kV/cm)

Weak Field – ε_r, tanδ vs. T @1kHz

PGT	Ga
PMT	Mn
PNT	Nb
PTT	Ta

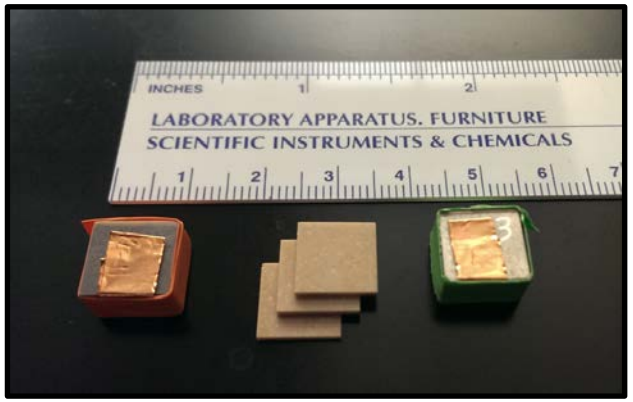


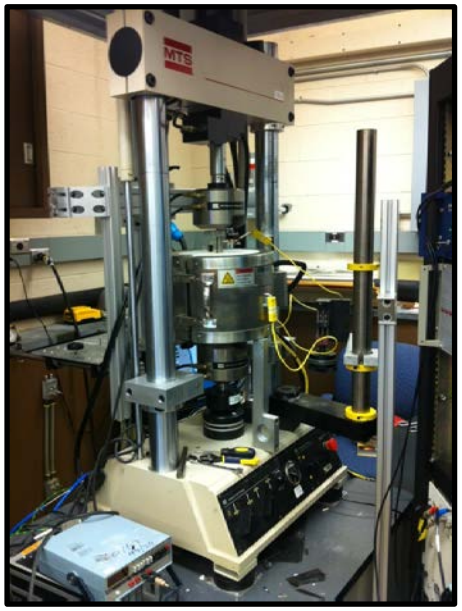
Comp.	T_c	RT tanδ	RT ε_r
BZZ2	422	0.017	783
PGT1	426	0.007	615
PGT2	430	0.009	606
PMT1	426	0.007	630
PMT2	426	0.008	518
PNT1	434	0.029	764
PNT2	426	0.021	728
PTT1	406	0.012	516
PTT2	418	0.03	846
PZT5A3	366	0.013	1910

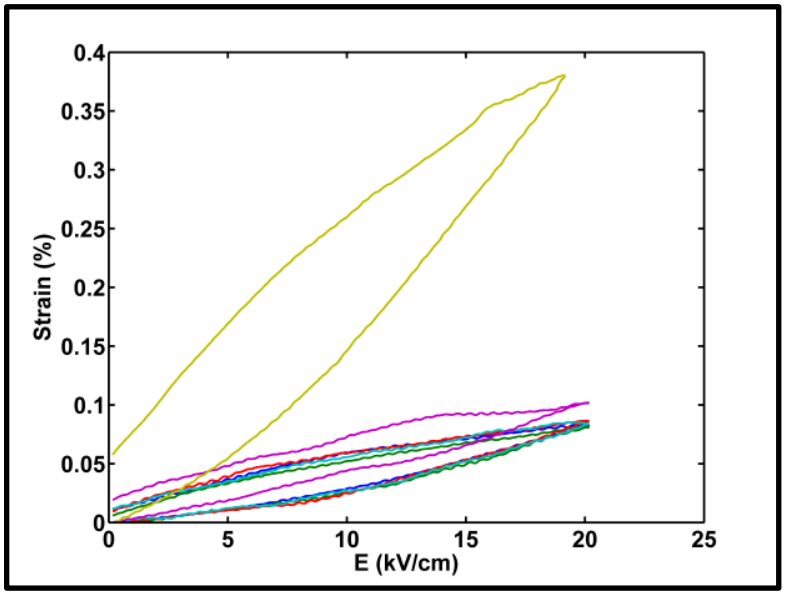
- Except for Ta, all dopants increase T_c
- Acceptor doping of Ga, Mn lowers tanδ by half
- At higher temperatures, Ga becomes lossy; Mn preferred for tanδ

*PZT5A3 provided by Morgan Electroceramics

Actuation

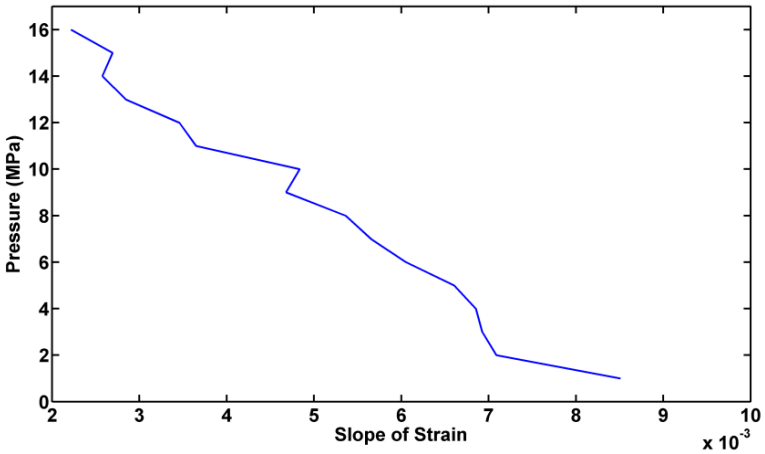






- 5 plates electrically in parallel, physically in series
- Stack has multiplicative effect on strain with only ~ 5% loss
- Mechanical set-up to measure displacement as a function of stress, temperature, frequency and electric field

Working on decreasing the noise



Summary

- New piezoelectrics with enhanced properties and greater operating temperature have been developed.
- Properties of interest has been shown as a function of temperature.
- Basic stack actuators with low loss in total stroke has been produced.
- A new instrument has been build to measure the properties as a function temperature, stress, electric field and frequency.
- Blocking force has been measured.
- Improvements on the instrumentation will be finished before the submission of the final report.