Poling, Reversing, and Cycling

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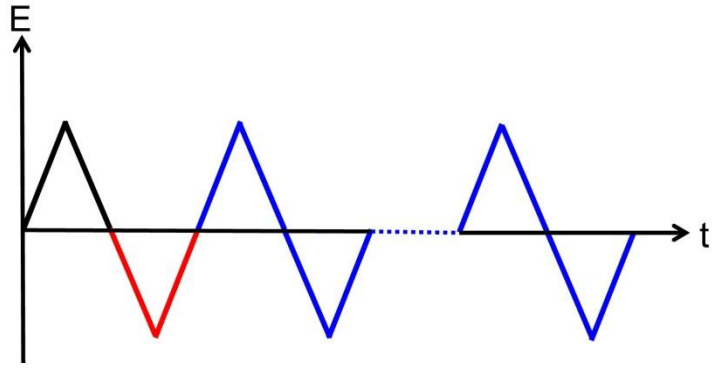
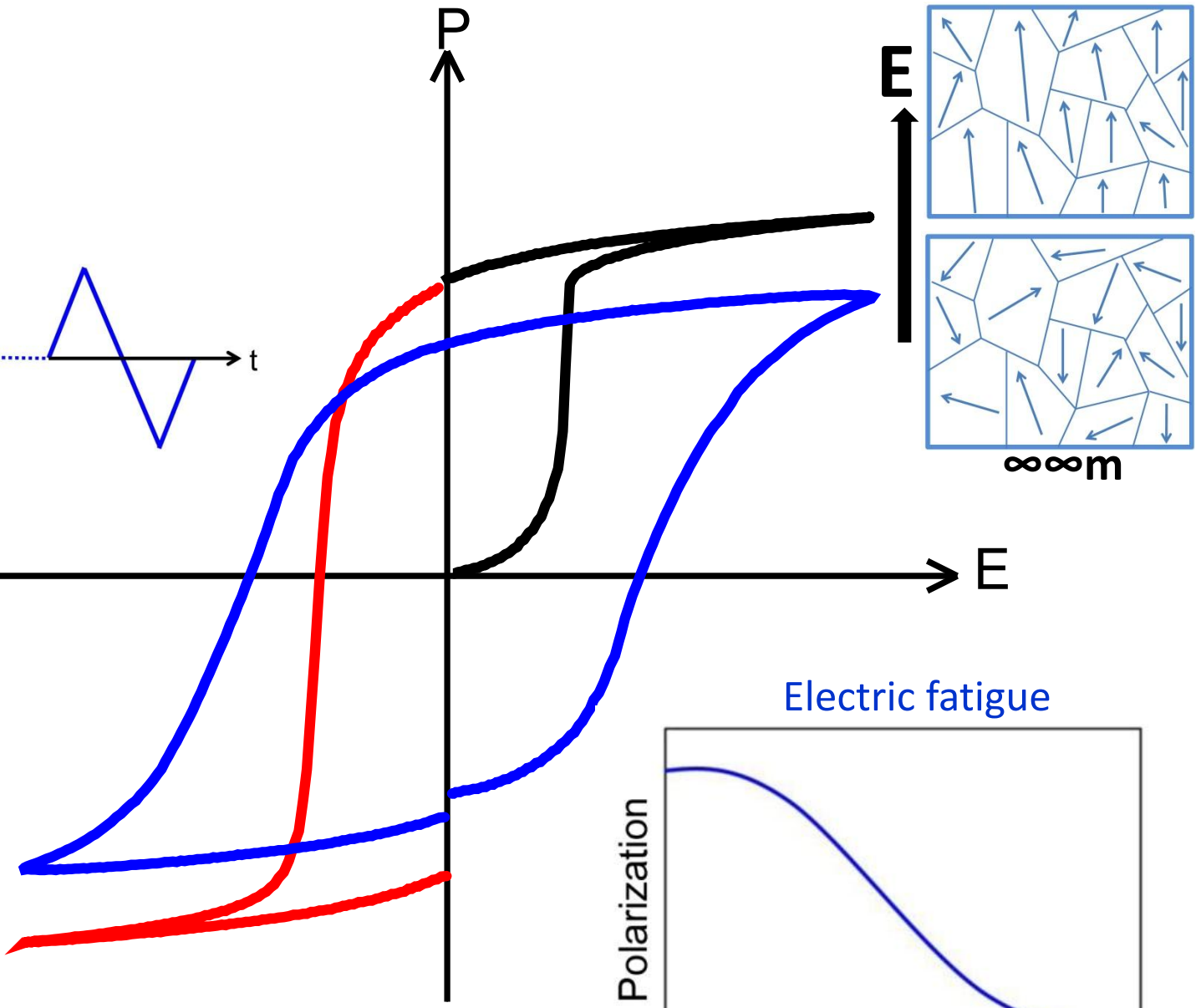
1. Poling
2. Reversing
3. Cycling



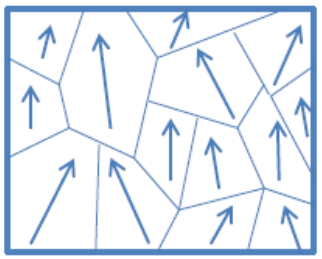


∞m

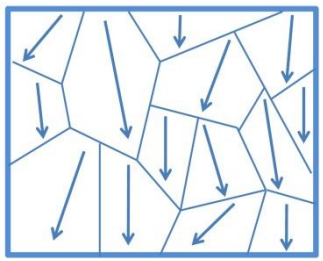
E

∞∞m

∞m



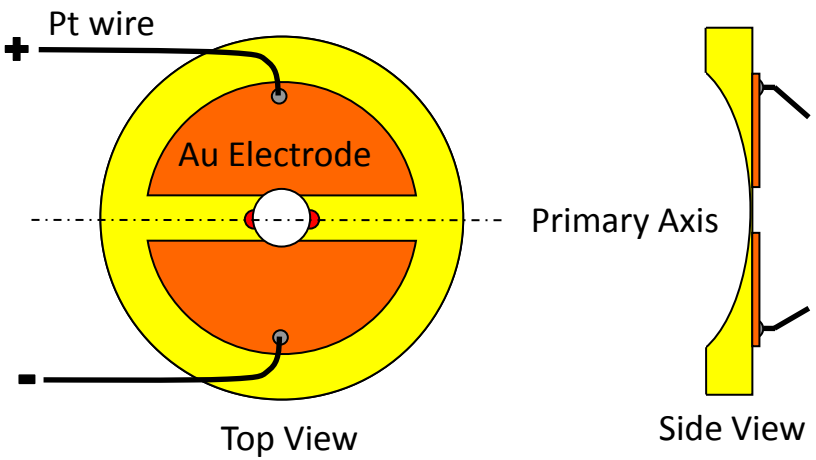
E

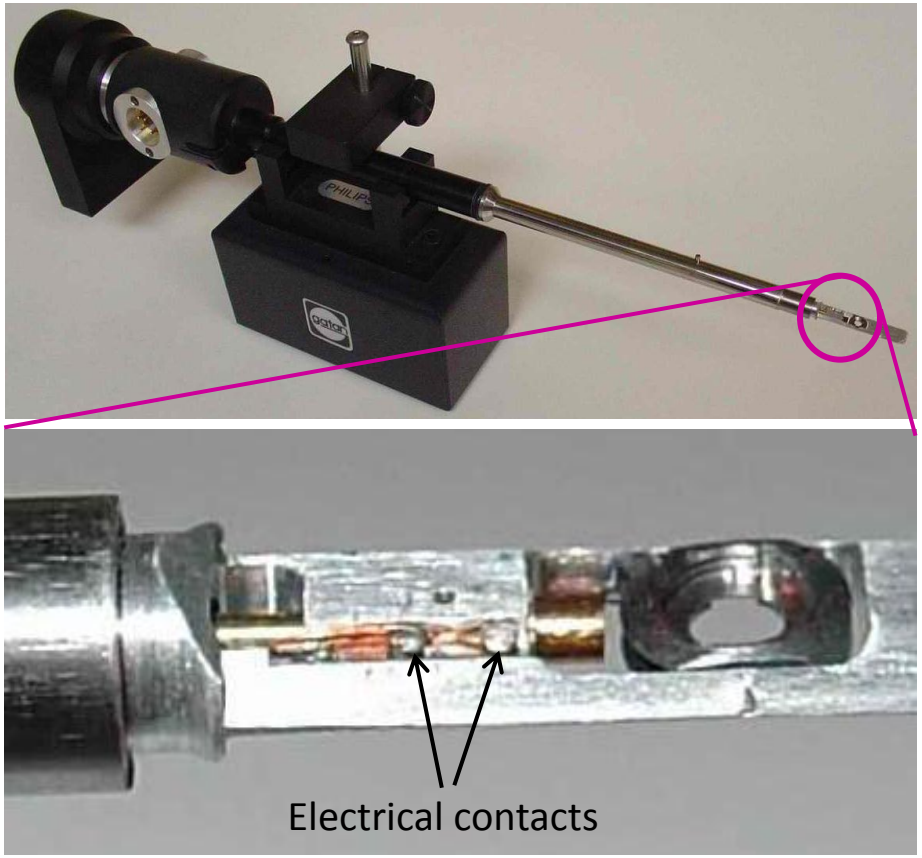


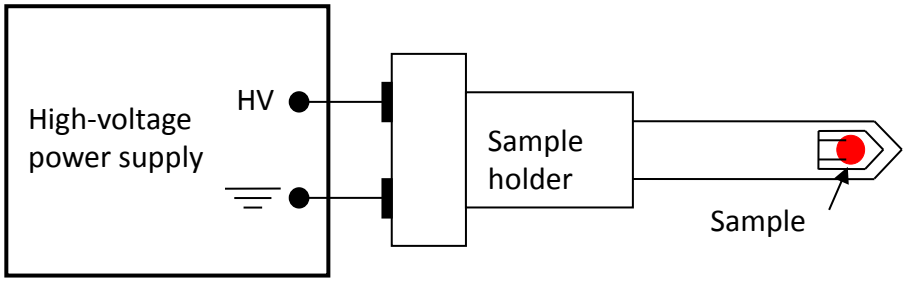
∞m

Electric fatigue

The E-field *in situ* TEM technique: Double-tilt stage







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H. He, and X. Tan, ***Phys. Rev. B*** 72, 024102/01-10 (2005).

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C. Ma, H. Guo, S.P. Beckman, and X. Tan, ***Phys. Rev. Lett.*** 109, 107602 (2012).

H. Guo, S.J. Zhang, S.P. Beckman, X. Tan, ***J. Appl. Phys.*** 114, 154102 (2013).

H.Z. Guo, C. Zhou, X.B. Ren, and X. Tan, ***Phys. Rev. B - Rapid Commun.*** 89, 100104(R) (2014).

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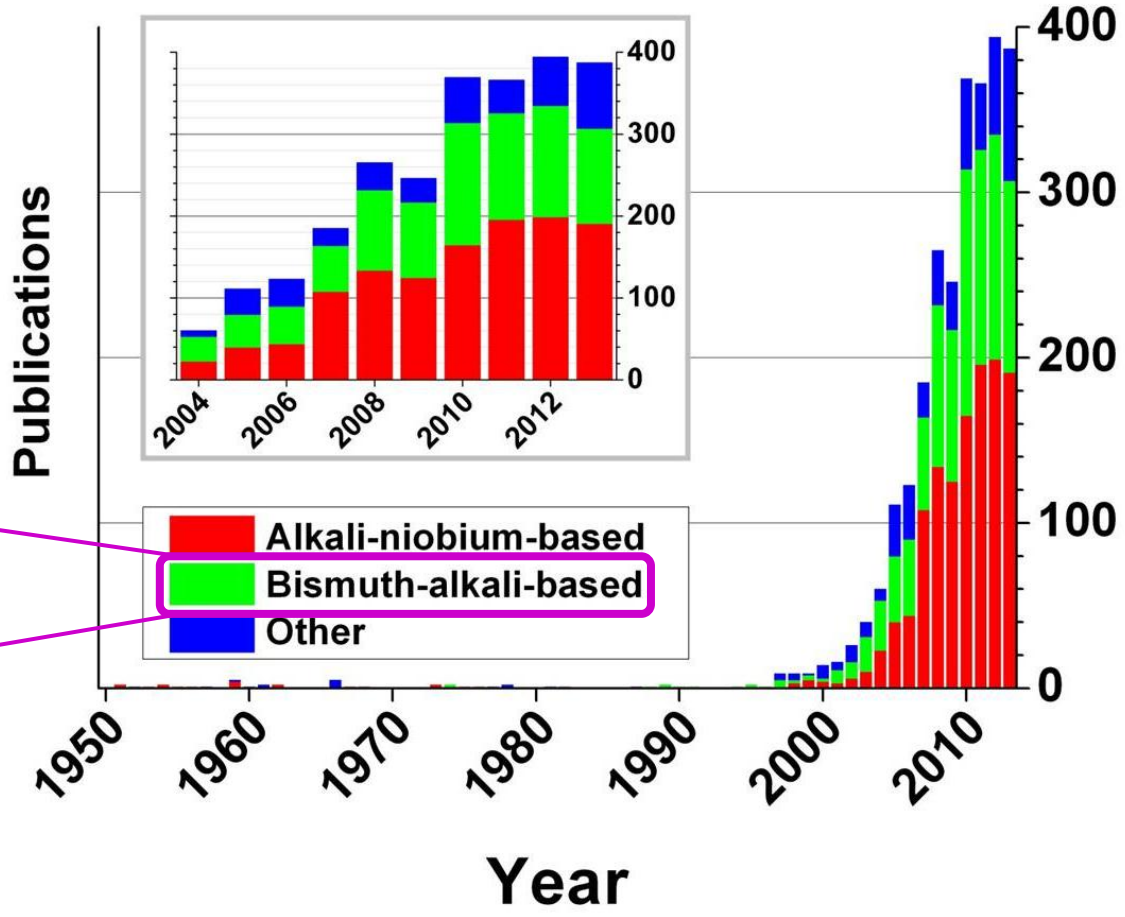
Annual refereed publications on lead-free piezoceramics

$[(Bi_{1/2}Na_{1/2})_{1-x}Ba_x]TiO_3$

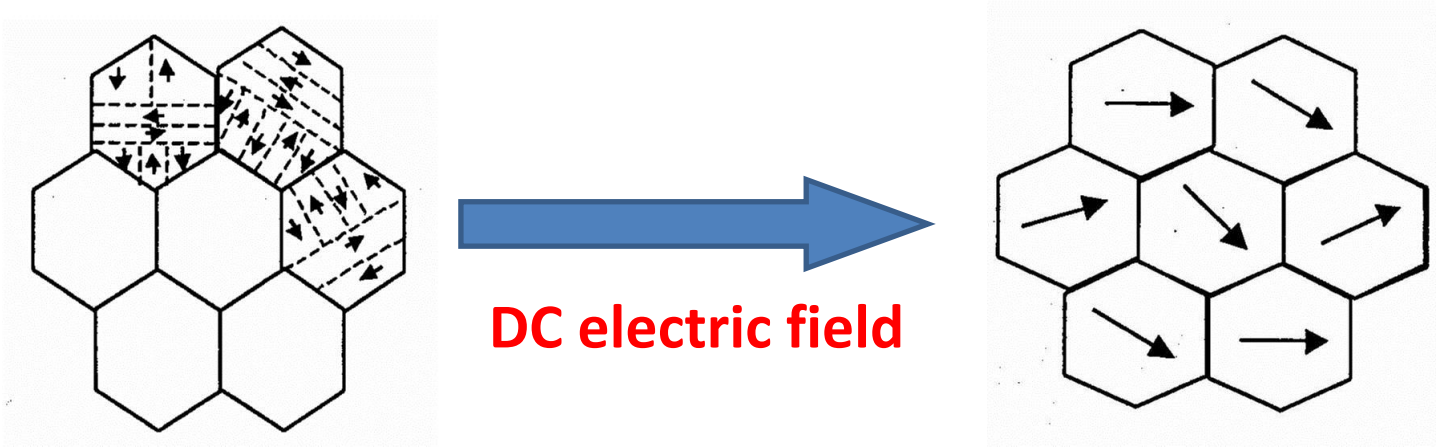


Courtesy of Prof. Jürgen Rödel

The **poling** of ferroelectric polycrystals:

Breaking the space inversion symmetry

Transforming non-piezoelectric to piezoelectric



Spherical symmetry

Curie group ∞∞m

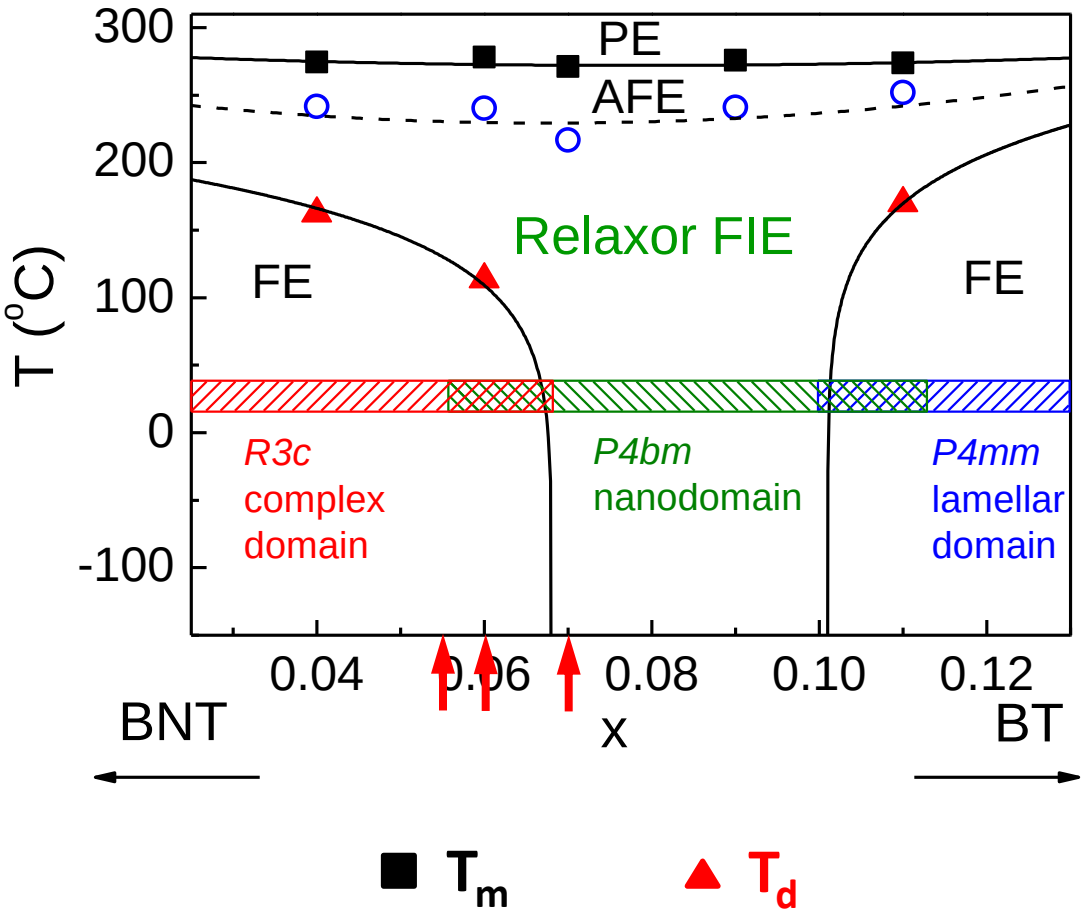
Non-piezoelectric

Conical symmetry

Curie group ∞m

Piezoelectric

The phase diagram of unpoled ceramics of $[(Bi_{1/2}Na_{1/2})_{1-x}Ba_x]TiO_3$



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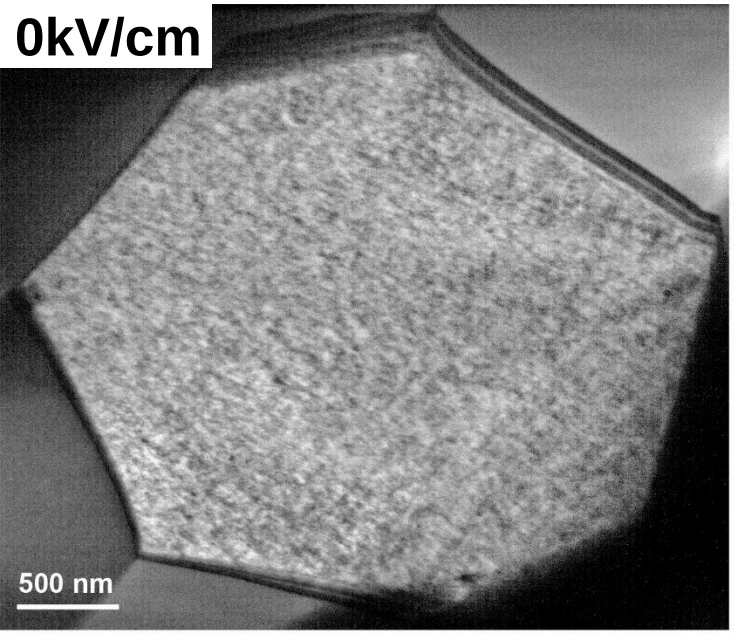
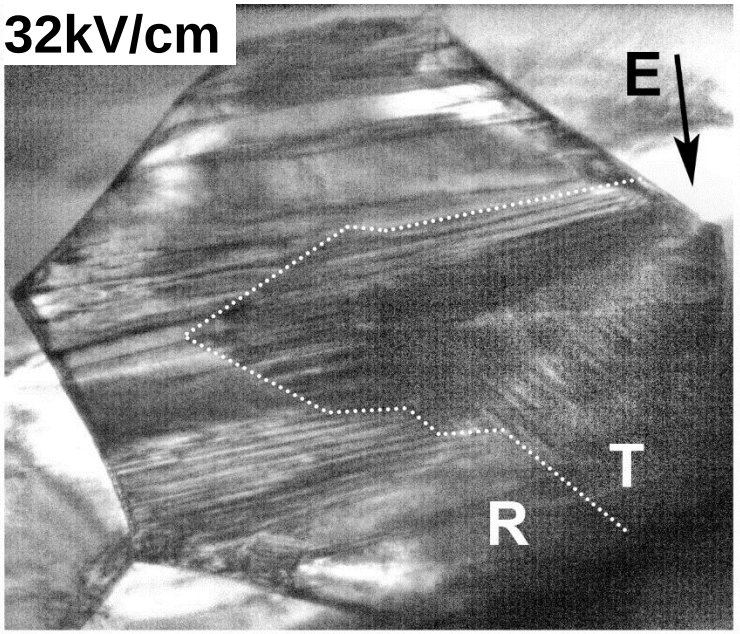
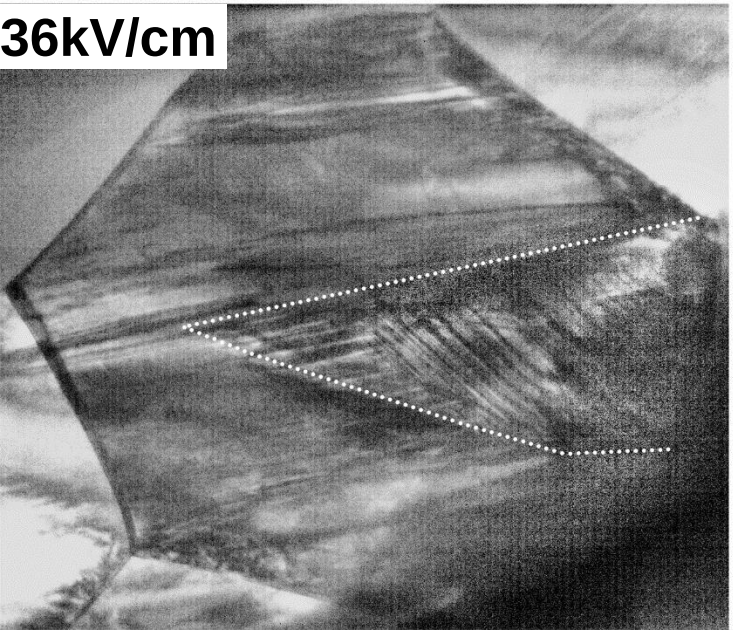
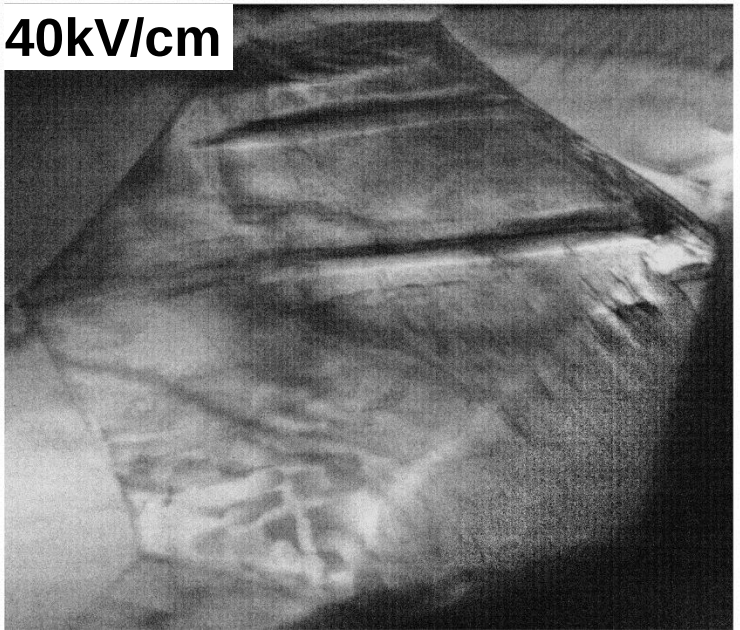
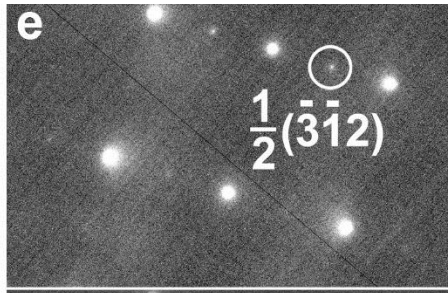
$[(Bi_{1/2}Na_{1/2})_{0.94}Ba_{0.06}]TiO_3$

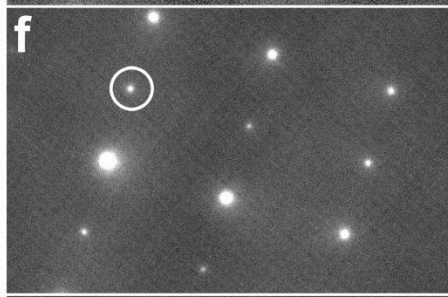


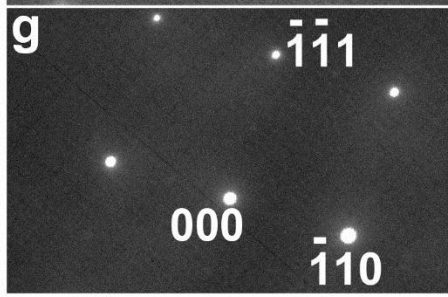


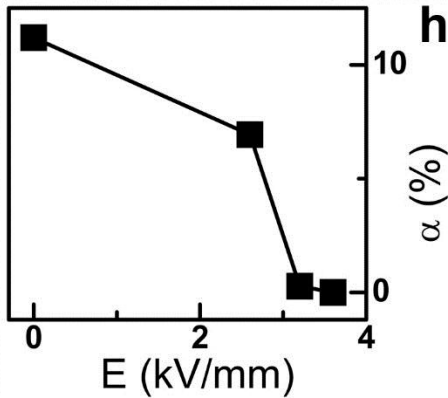






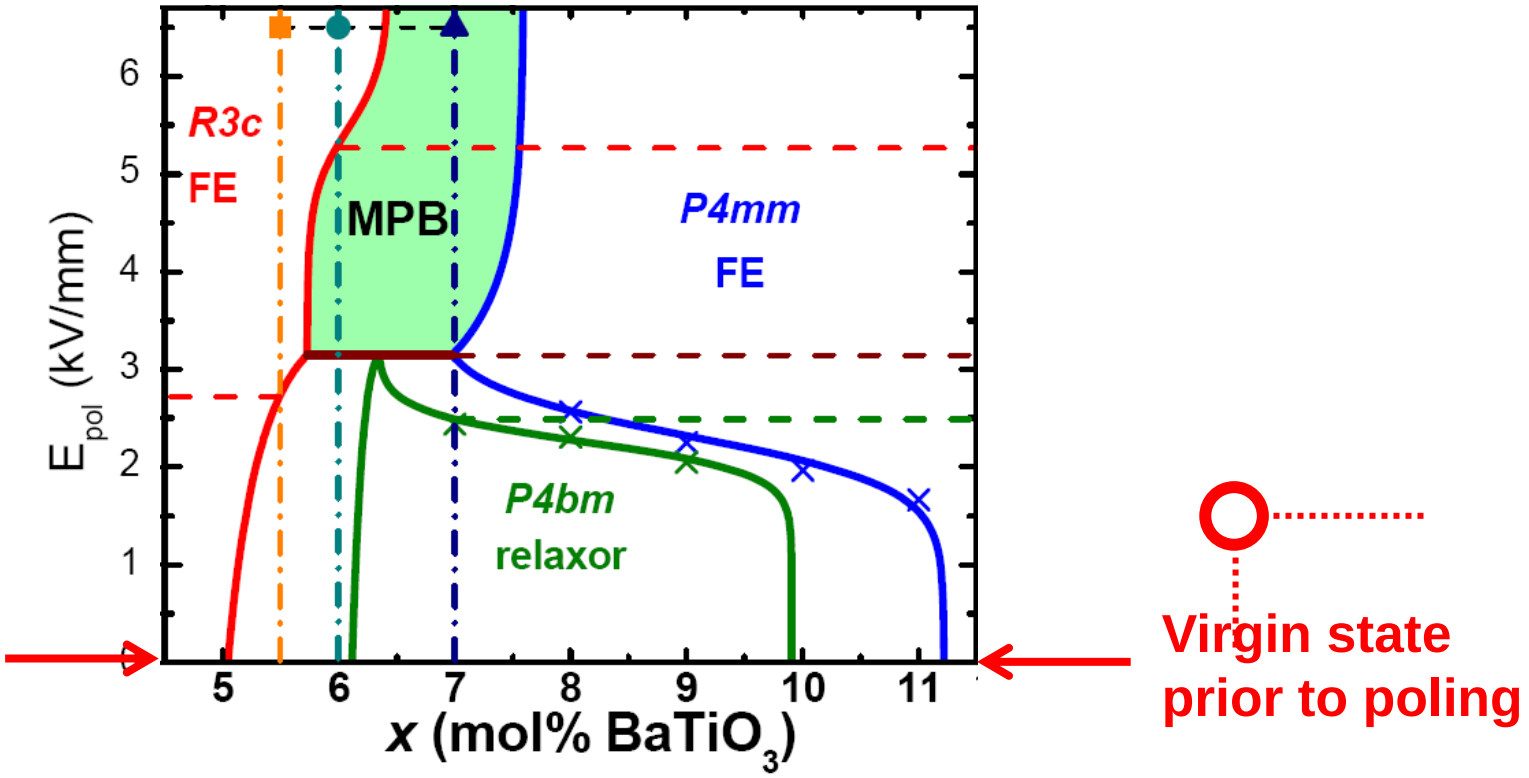




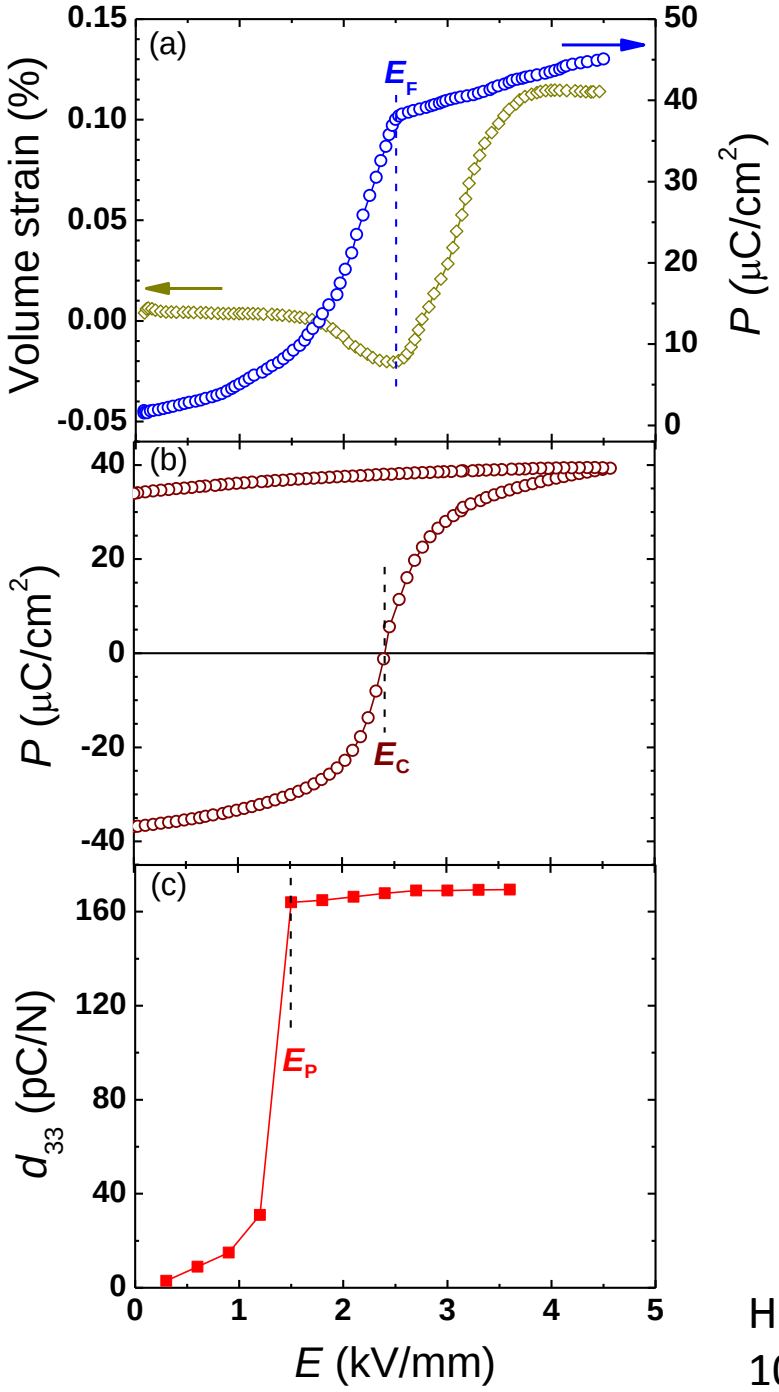


Phase transitions & the corresponding d_{33}

Poling: 25°C, at field levels from 1.5 to 6.5 kV/mm.
After 24 hours, d_{33} was measured at 10 spots across the electrode surface.



C. Ma, H. Guo, S.P. Beckman, and X. Tan, ***Phys. Rev. Lett.*** 109, 107602 (2012).



Poling below E_C?

E_F: the critical field to transform to ferroelectric phases

E_C: the critical field to switch ferroelectric domains

E_P: the critical field to develop saturating piezoelectric d_{33}

For $[(Bi_{1/2}Na_{1/2})_{0.93}Ba_{0.07}]TiO_3$

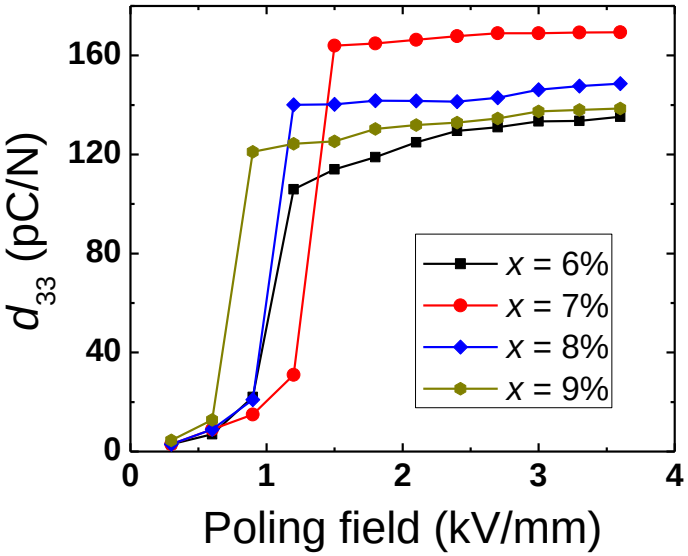
E_F = 2.5 kV/mm

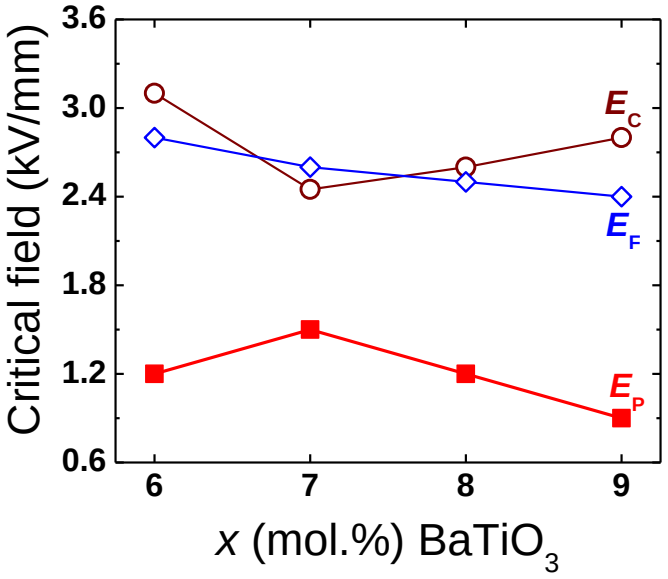
E_C = 2.4 kV/mm

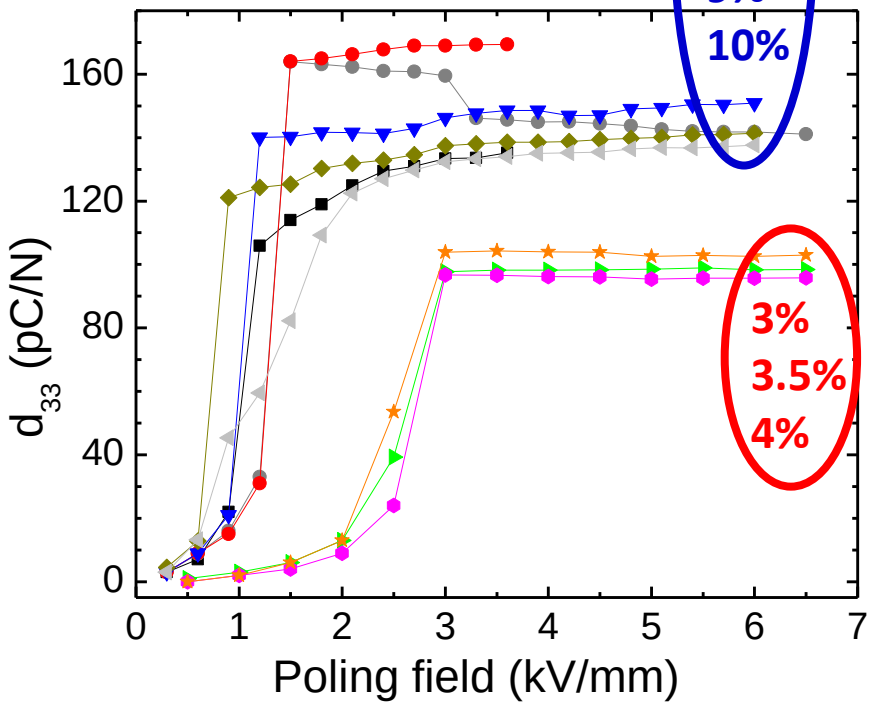
E_P = 1.5 kV/mm

H. Guo, C. Ma, X. Liu, and X. Tan, ***Appl. Phys. Lett.*** 102, 092902 (2013).

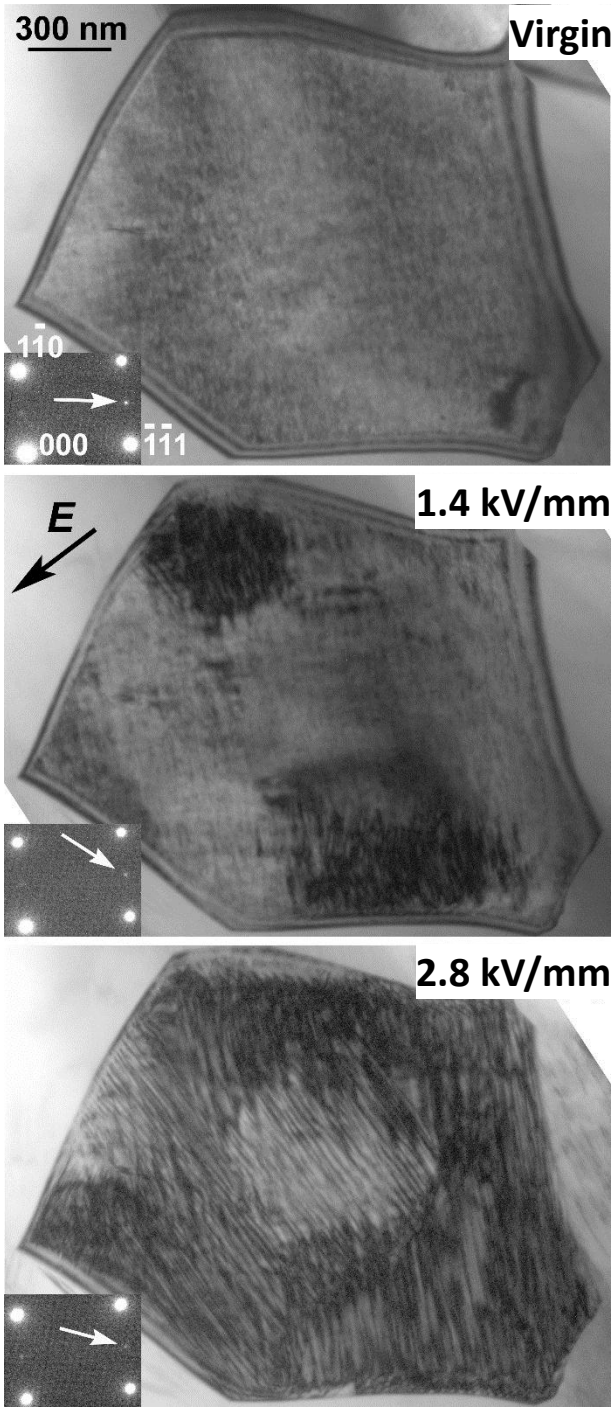
Poling of the ***P4bm*** phase!



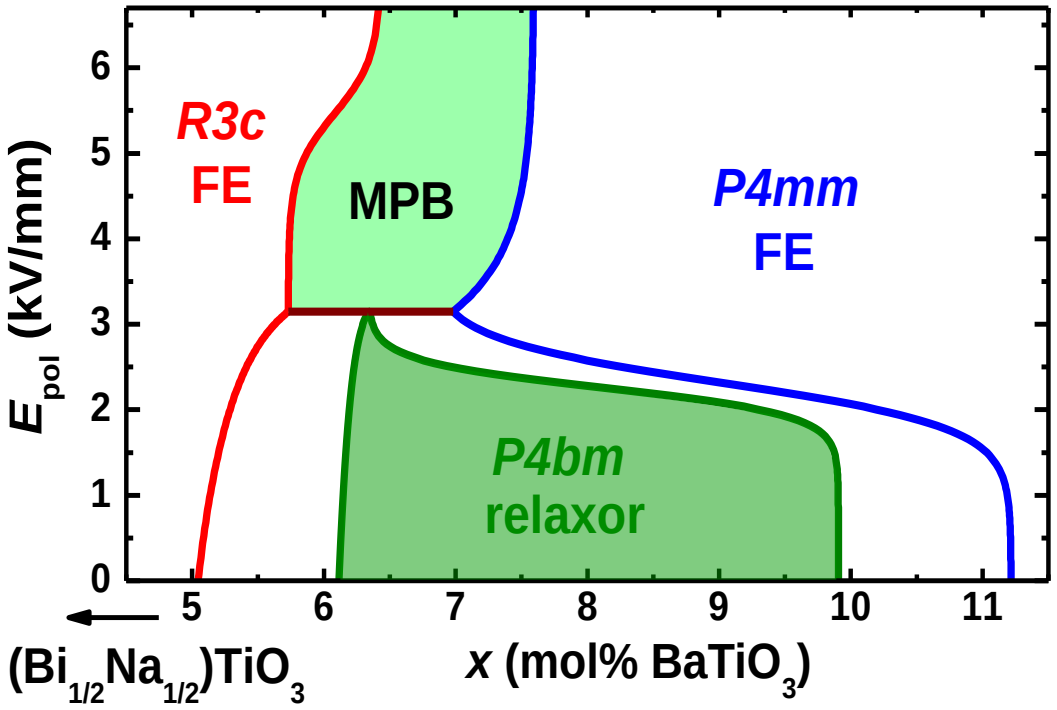




H. Guo, C. Ma, X. Liu, and X. Tan, ***Appl. Phys. Lett.*** 102, 092902 (2013).

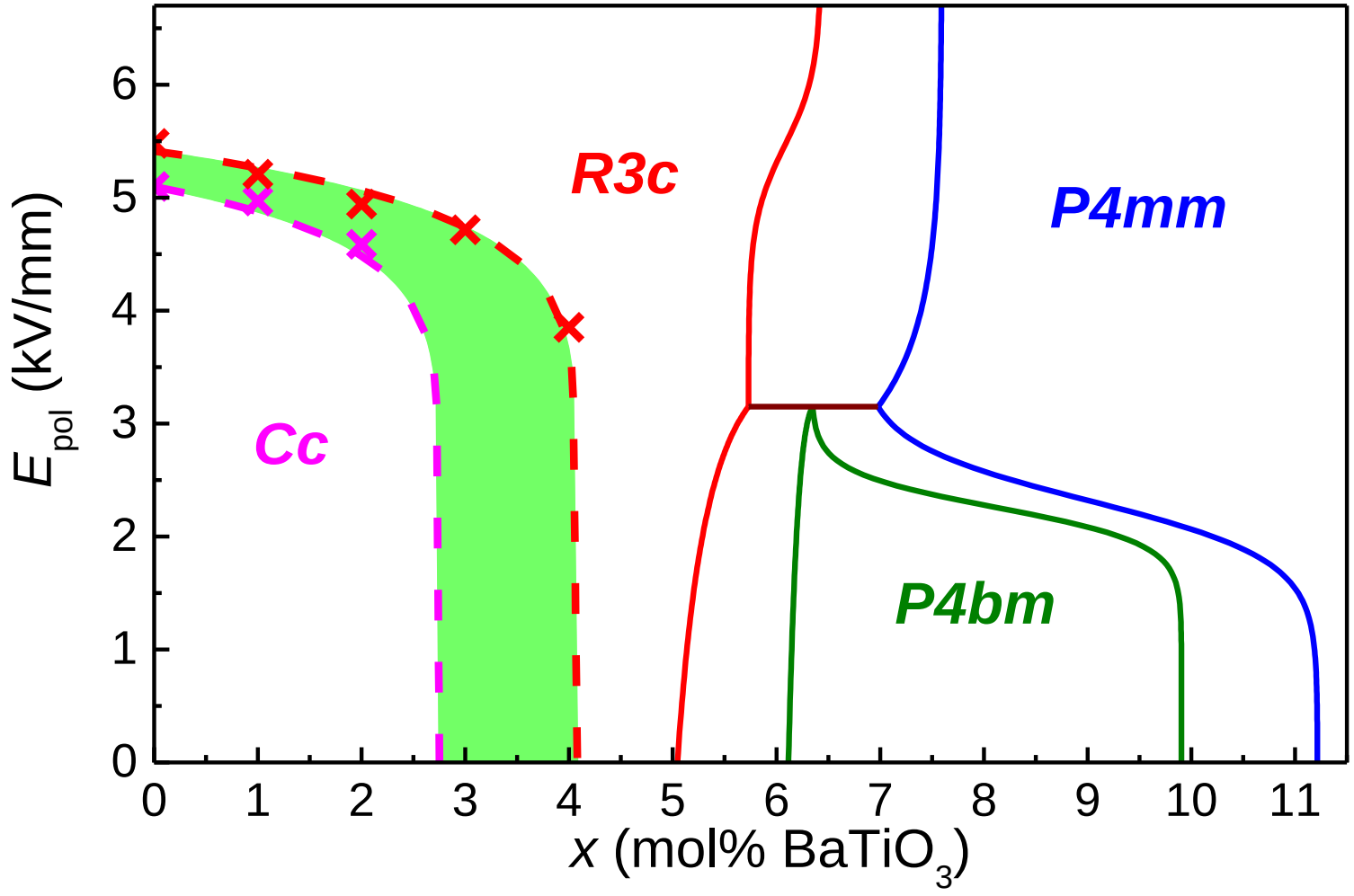


Poling of the *P4bm* relaxor phase



H. Guo, C. Ma, X. Liu, and X. Tan, ***Appl. Phys. Lett.*** 102, 092902 (2013).

The updated phase diagram with the *Cc* phase



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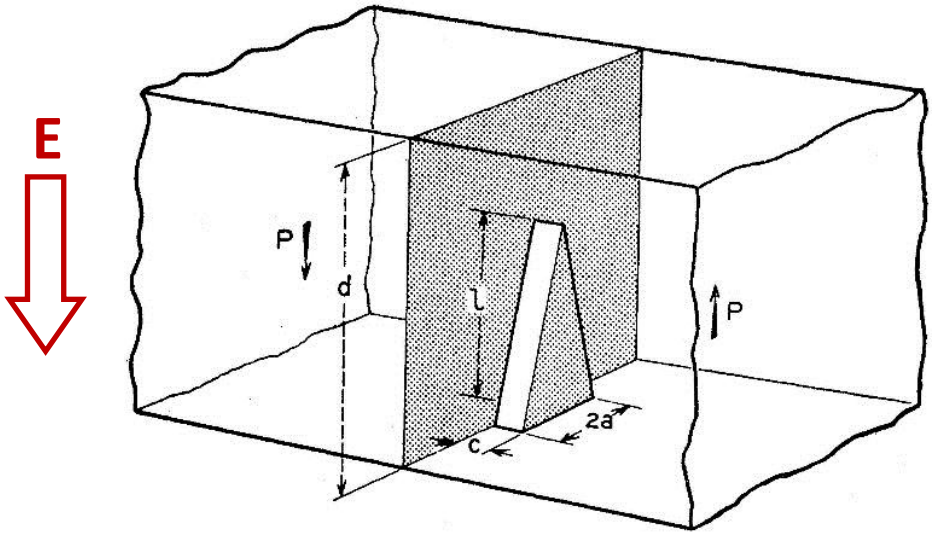
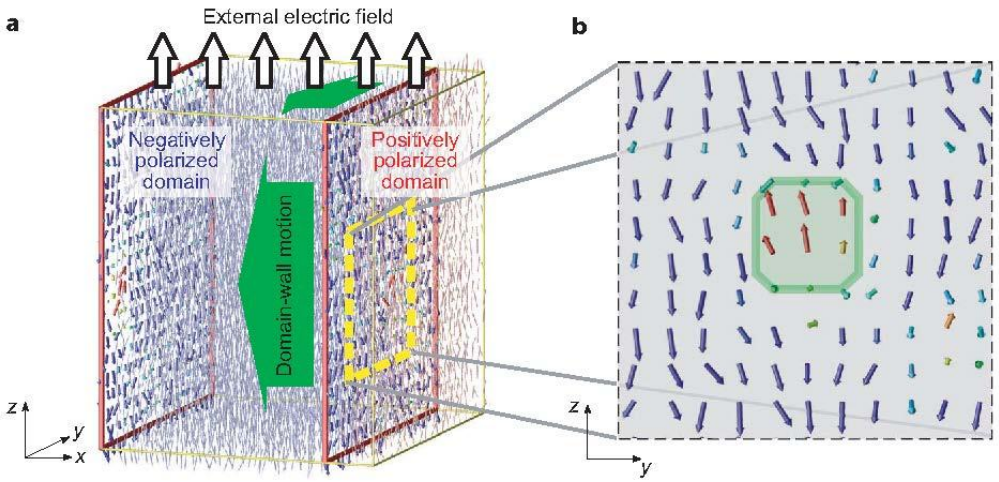
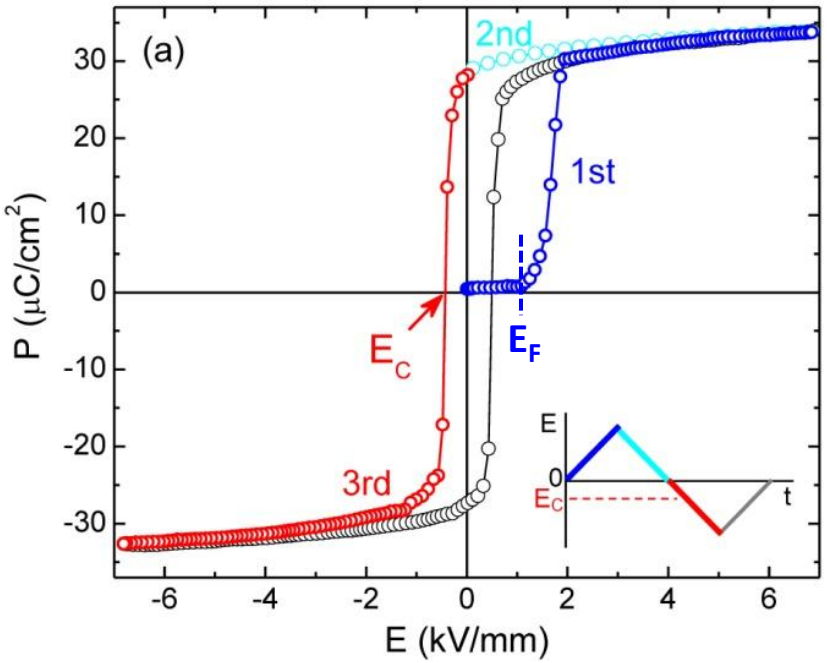
The **reversing** of ferroelectric polarization

Normal ferroelectric





Induced ferroelectric



PNZST 43/8/2

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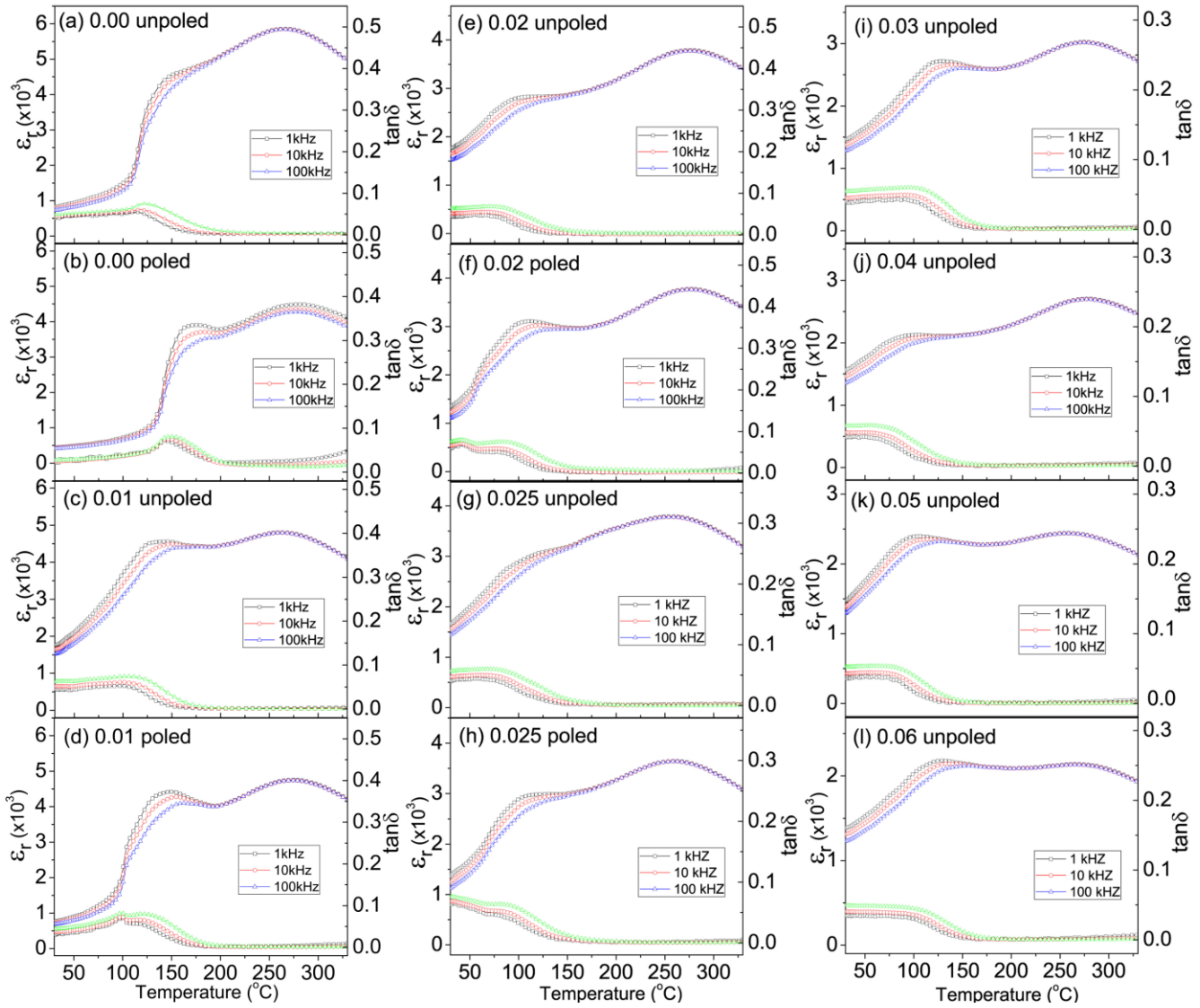
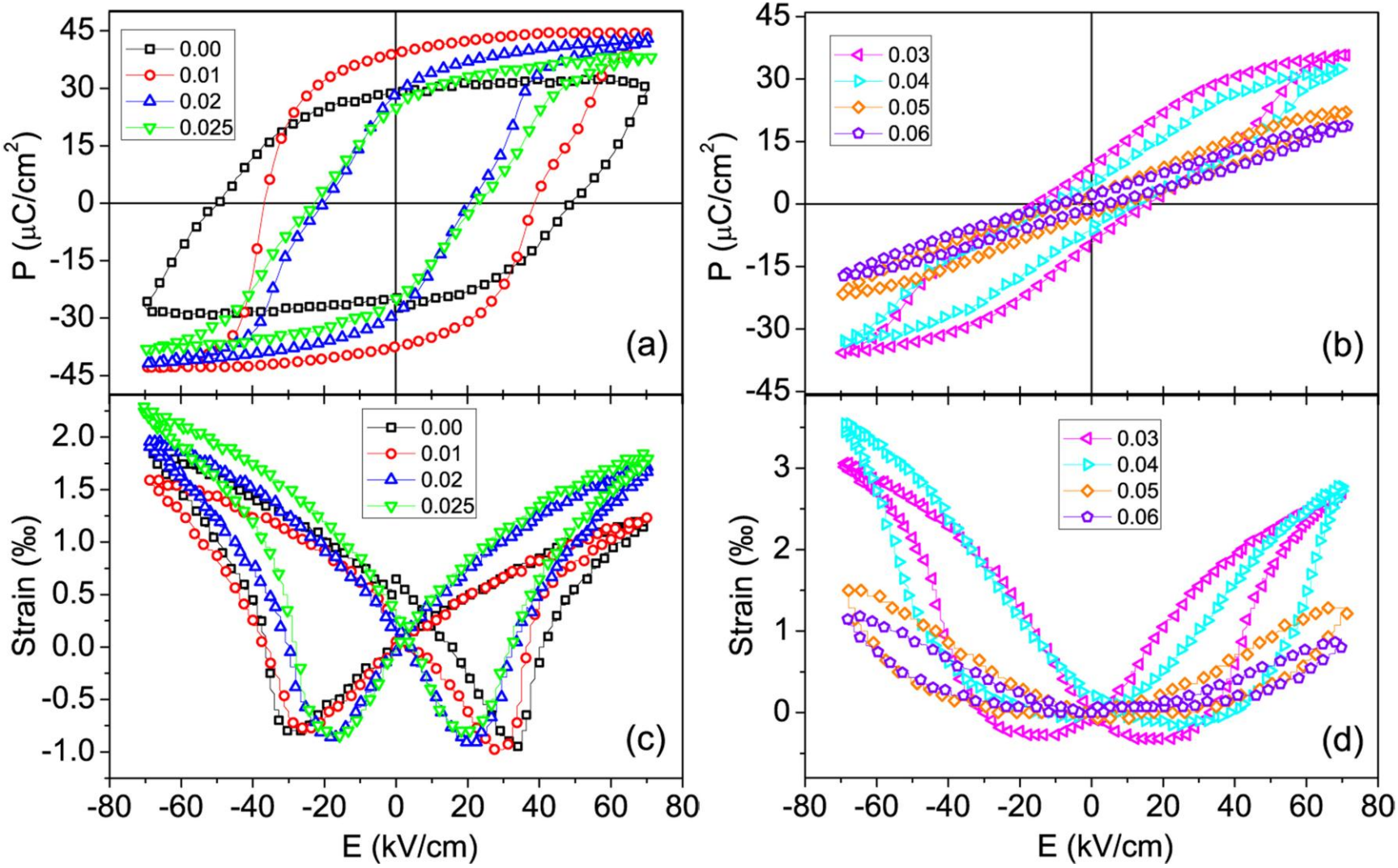
$[(Bi_{1/2}Na_{1/2})_{0.95}Ba_{0.05}]_{1-x}La_xTiO_3$



X.M. Liu, H.Z. Guo, and X. Tan, ***J. Euro. Ceram. Soc.*** 34, 2997 (2014).

$[(Bi_{1/2}Na_{1/2})_{0.95}Ba_{0.05}]_{1-x}La_xTiO_3$



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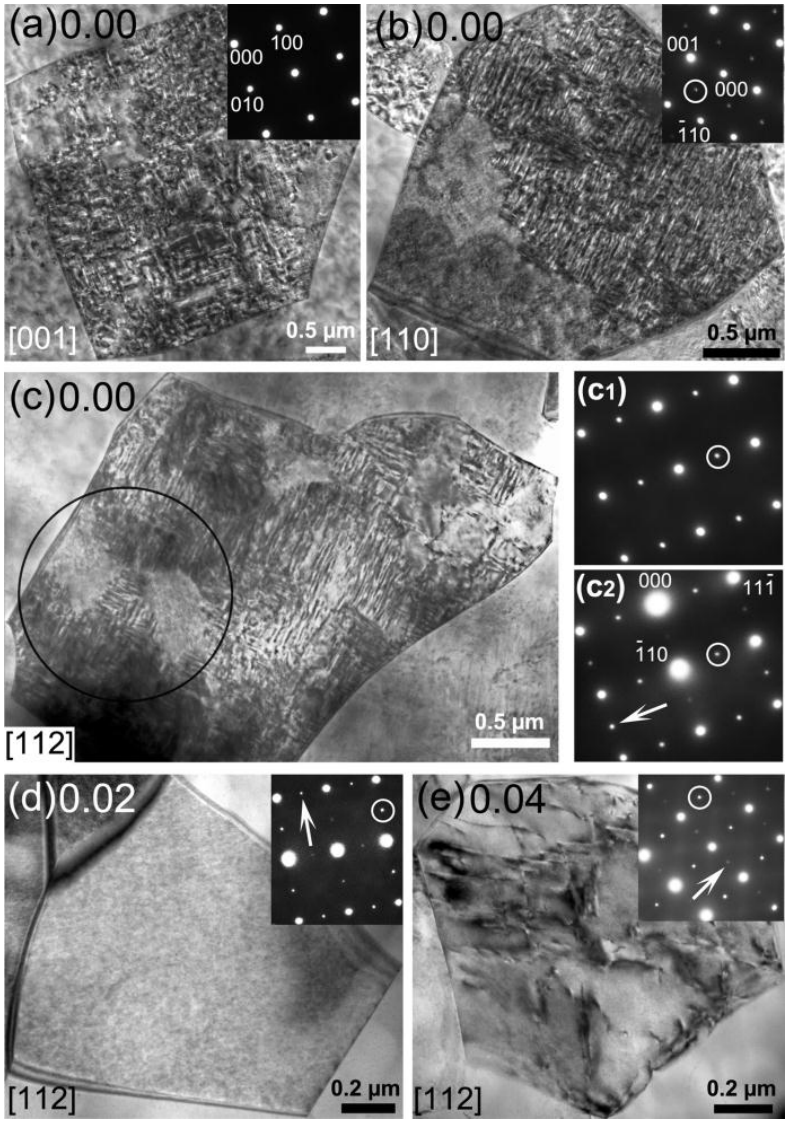
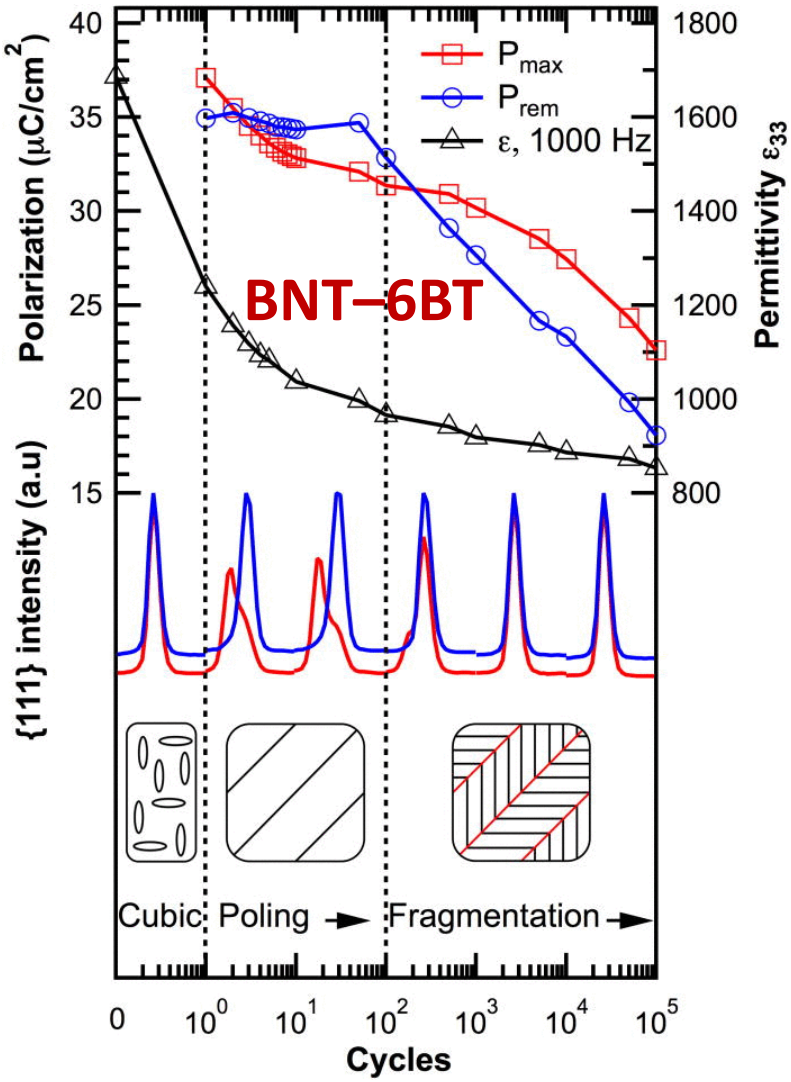


X.M. Liu, H.Z. Guo, and X. Tan, ***J. Euro. Ceram. Soc.*** 34, 2997 (2014).

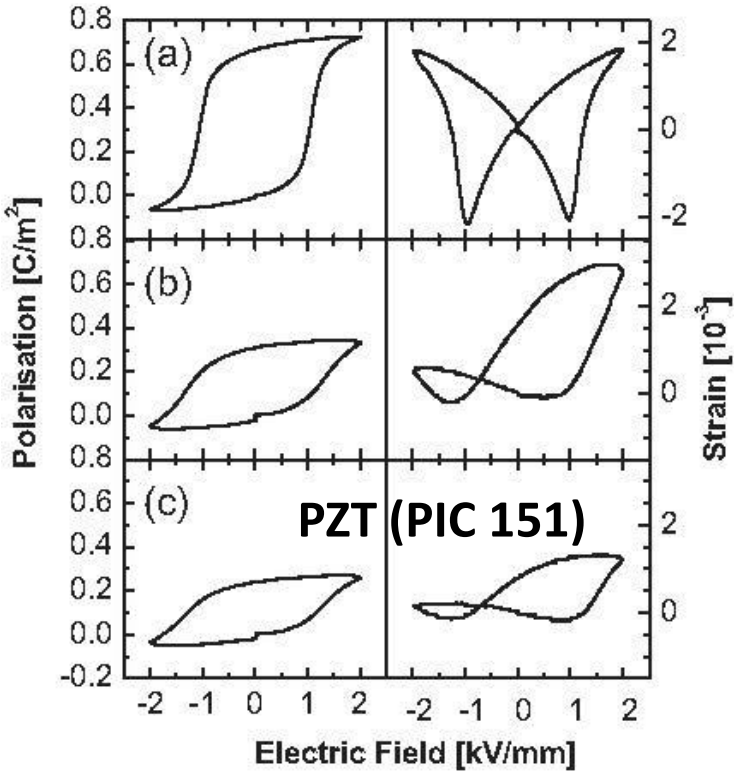
The **cycling** of ferroelectric polarization



J. Am. Ceram. Soc., 1 16 (2014)
DOI: 10.1111/jace.12811

Electric Fatigue of Lead-Free Piezoelectric Materials

Julia Glaum† and Mark Hoffman



D.C. Lupascu and J. Rödel, ***Adv. Eng. Mater.*** 7, 882 (2005).
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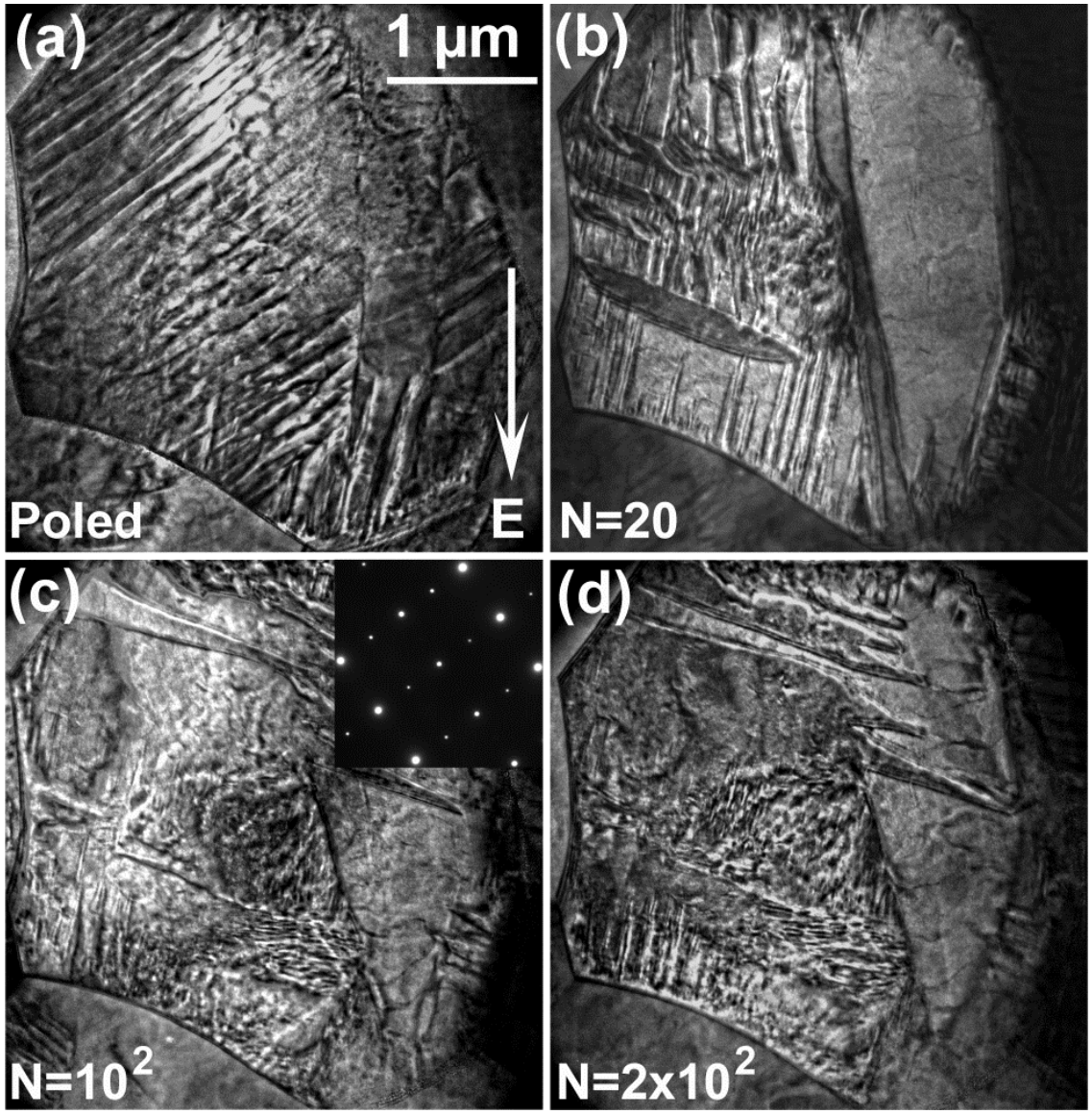
$[(Bi_{1/2}Na_{1/2})_{0.95}Ba_{0.05}]_{0.98}La_{0.02}TiO_3$

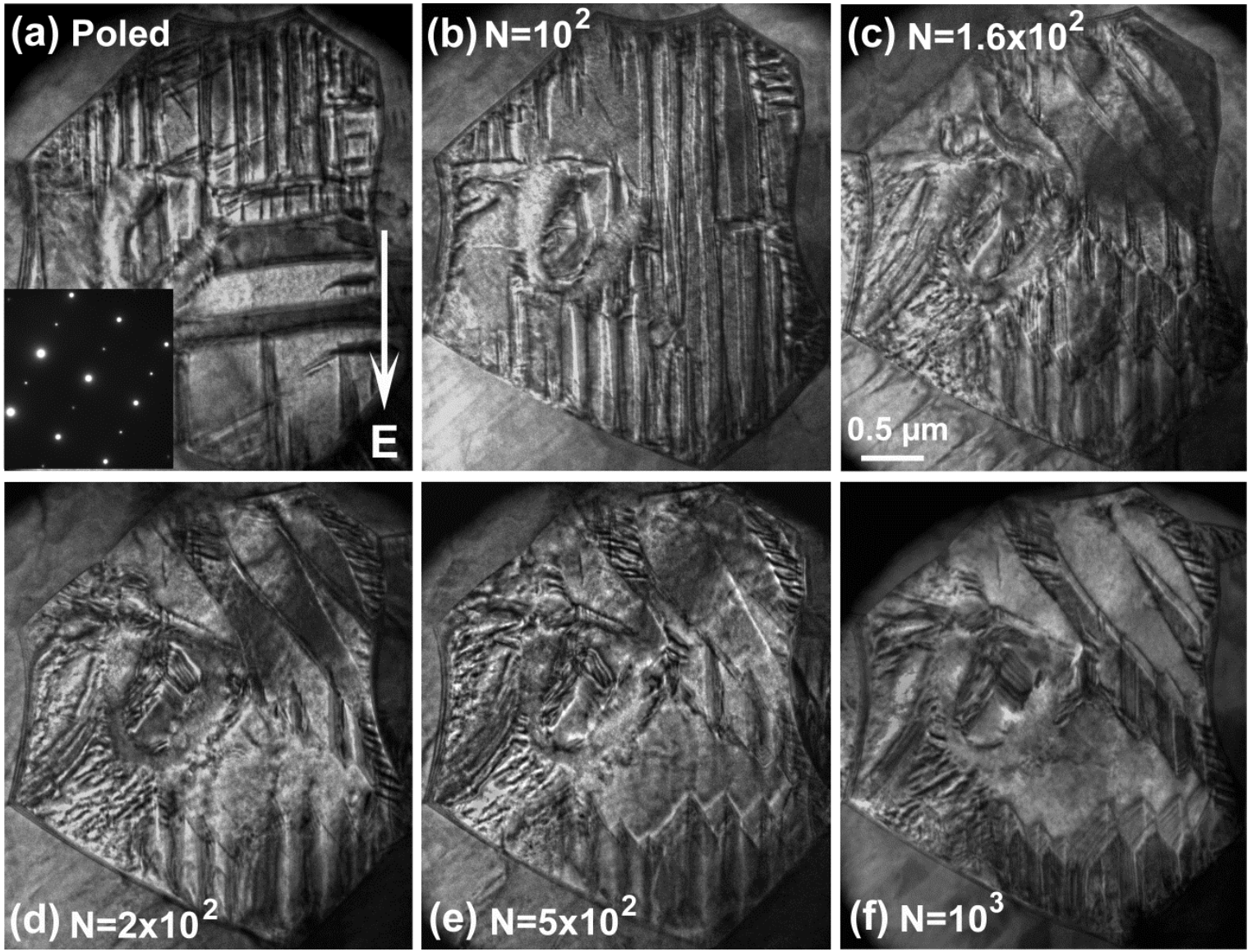


ZA [112]

Cycling at ±30kV/cm at 1 Hz.

Micrographs recorded at zero field.

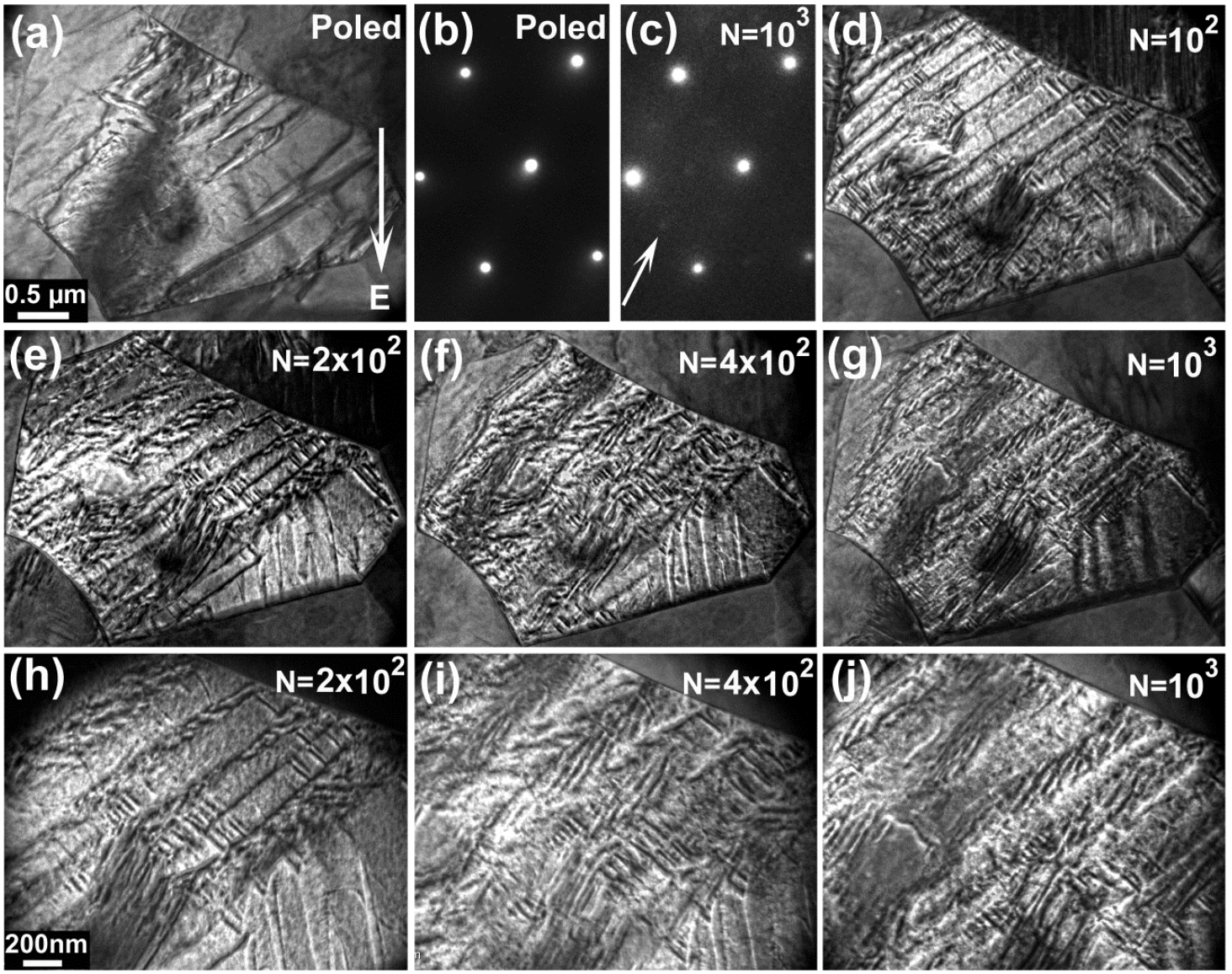
$[(Bi_{1/2}Na_{1/2})_{0.95}Ba_{0.05}]_{0.98}La_{0.02}TiO_3$



ZA [112]

The same TEM specimen

$[(Bi_{1/2}Na_{1/2})_{0.95}Ba_{0.05}]_{0.98}La_{0.02}TiO_3$



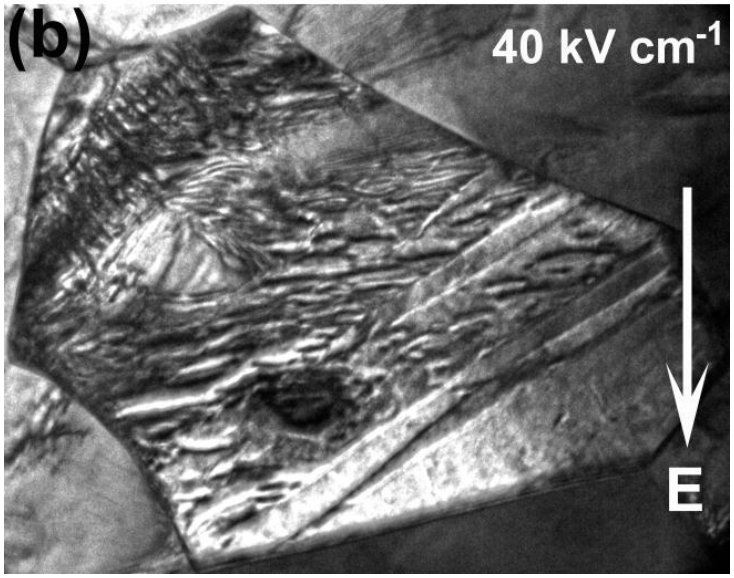
ZA [111]

The same TEM specimen

$[(Bi_{1/2}Na_{1/2})_{0.95}Ba_{0.05}]_{0.98}La_{0.02}TiO_3$

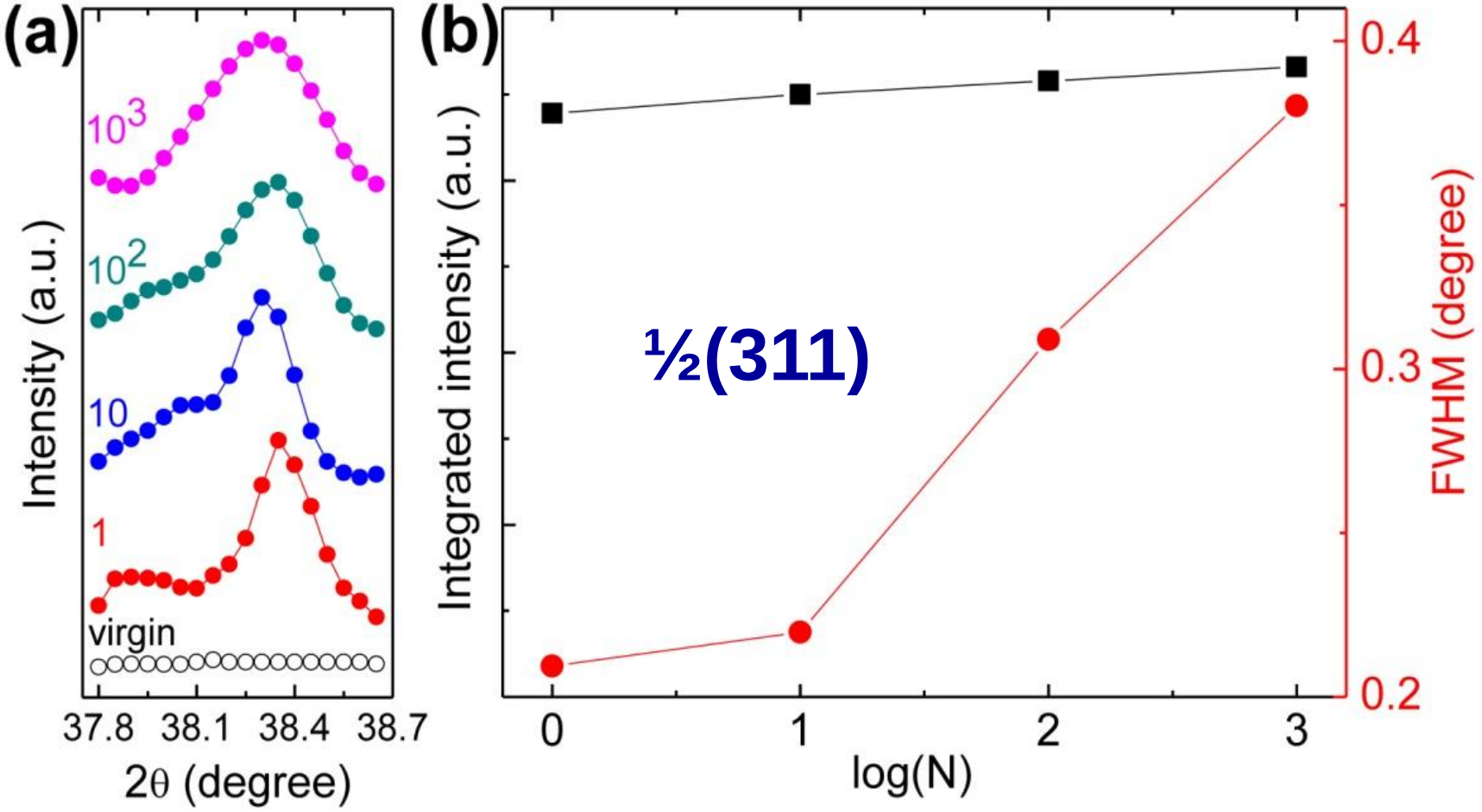
After initial poling at 30kV/cm

ZA [111]



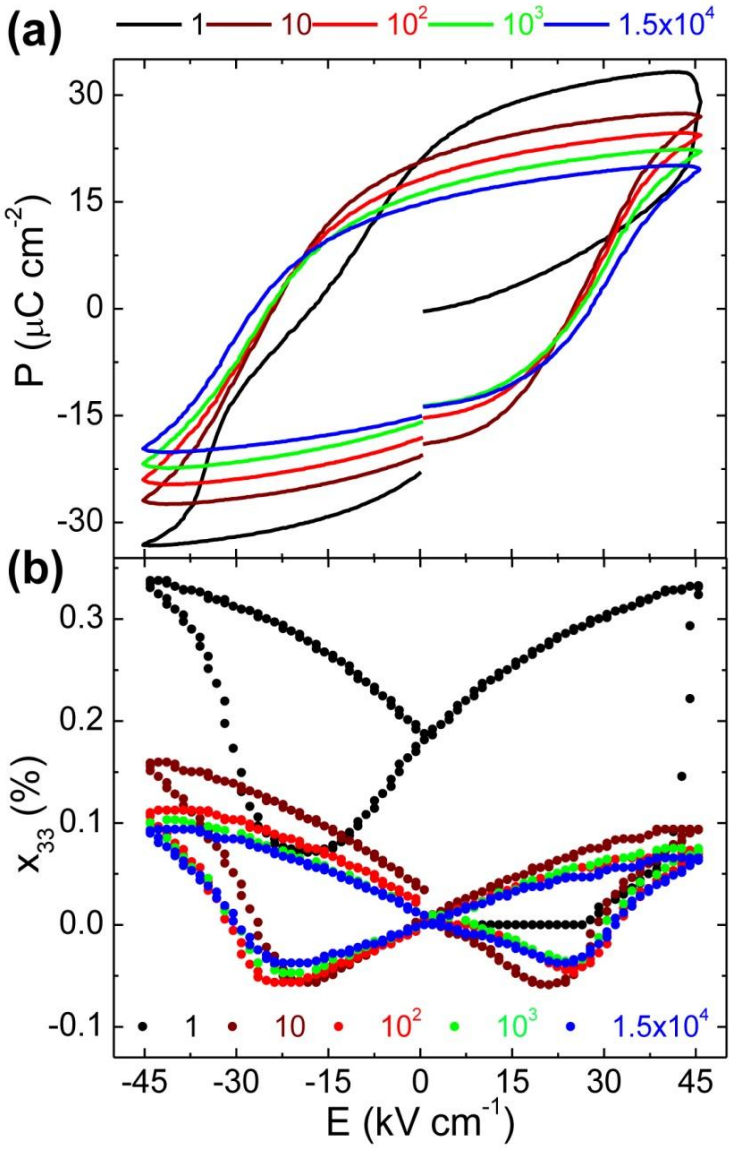
At 40kV/cm after 10^3 cycles at ±30kV/cm

X-ray diffraction on a bulk specimen

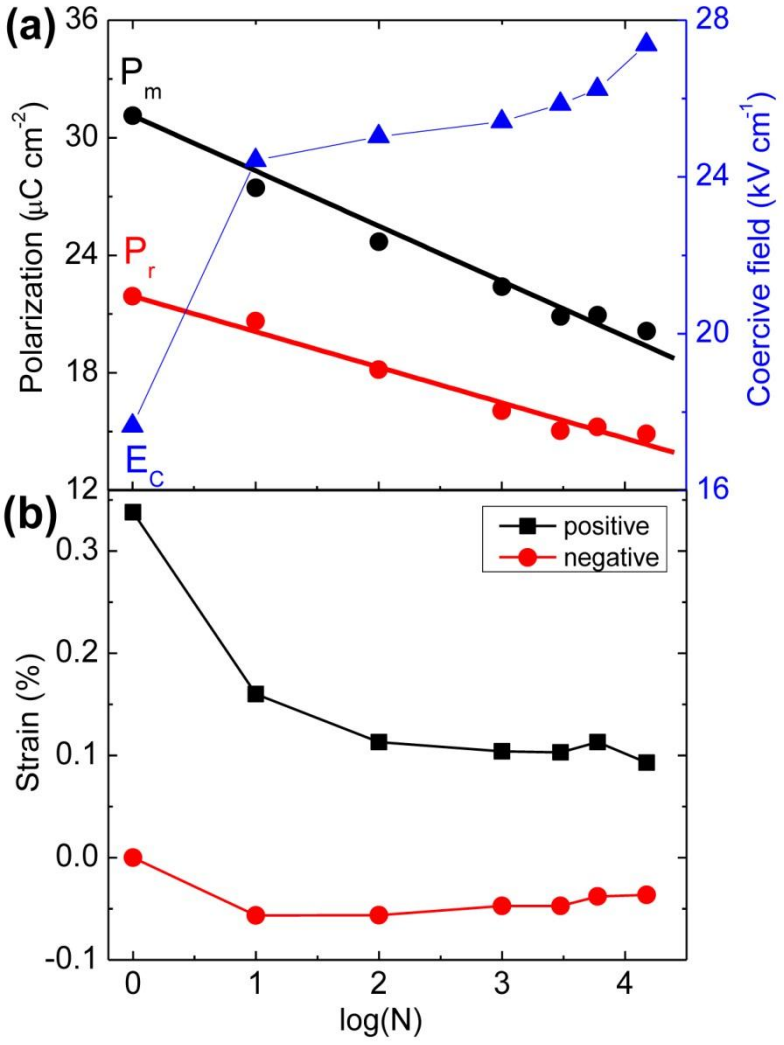


Estimated domain size reduces from 40 nm to 20 nm after 10^3 cycles (±45 kV/cm at 4Hz).

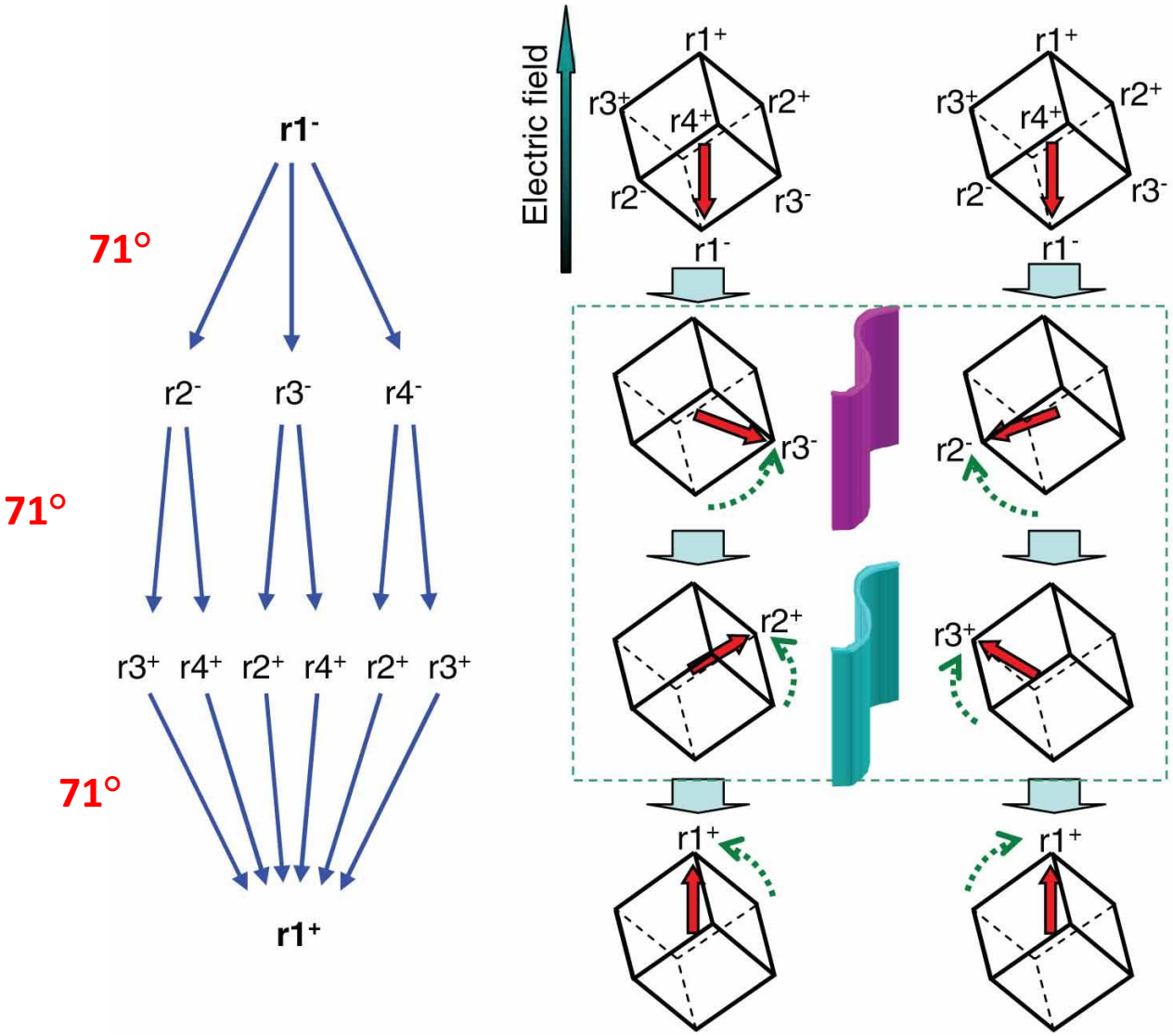
Macroscopic behavior in bulk specimens



$$P = P_0 + A\log(N)$$



Why it happens?



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Baek, S.H. et al., ***Adv. Mater.*** 23, 1621 (2011).

Conclusions

$[(Bi_{1/2}Na_{1/2})_{1-x}Ba_x]TiO_3$–based ceramics:

- Phase transitions occur during electrical **poling.**
- Phase transitions occur during polarization **reversing.**
- Domain fragmentation occurs during electrical **cycling.**

Acknowledgements

- TEM access at Ames Laboratory, US-DOE.

THE Ames Laboratory
Creating Materials & Energy Solutions

- Financial support from National Science Foundation.

NSF

- Support and collaborations with Prof. Jürgen Rödel