15th Korea-U.S. Forum on Nanotechnology

Epitaxial piezoelectric heterostructures for ultrasound micro-transducers

Seung-Hyub Baek

Center for Electronic Materials
Korea Institute of Science and Technology (KIST)

Korea Institute of Science and Technology

Security issue for mobile electronics

Security system for mobile electronics is required !

- Personal information
- Banking

Highly secured

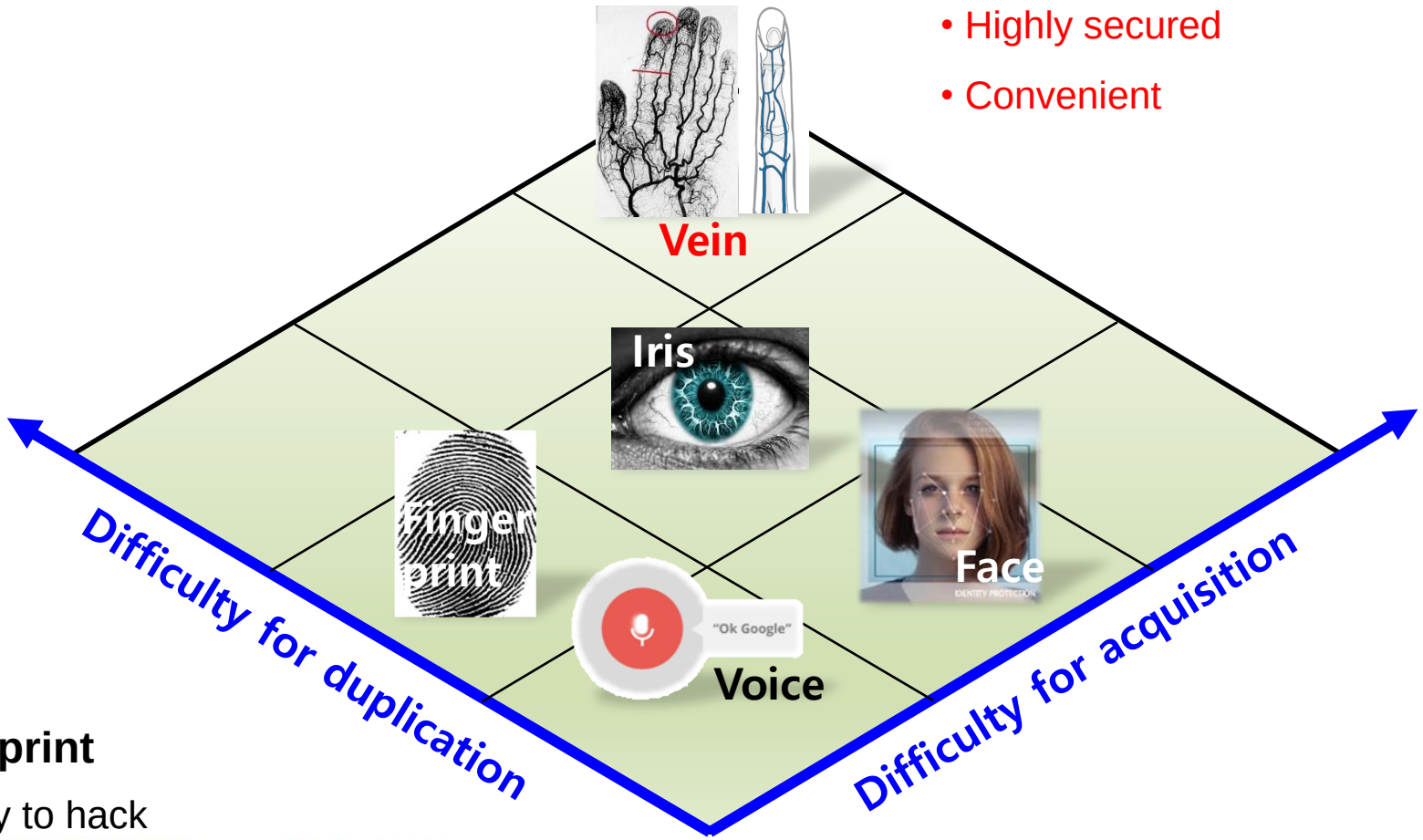
Convenient

Small, low-power consuming

Biometrics-based authentication systems

Fingervein

- Highly secured
- Convenient

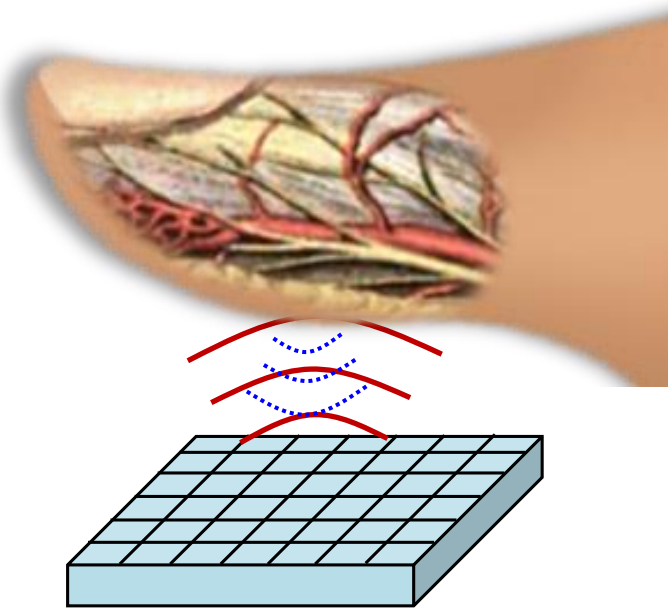


Fingerprint

- Easy to hack

How to Hack any FingerPrint Using Glue
Creative
조회수 5,335회

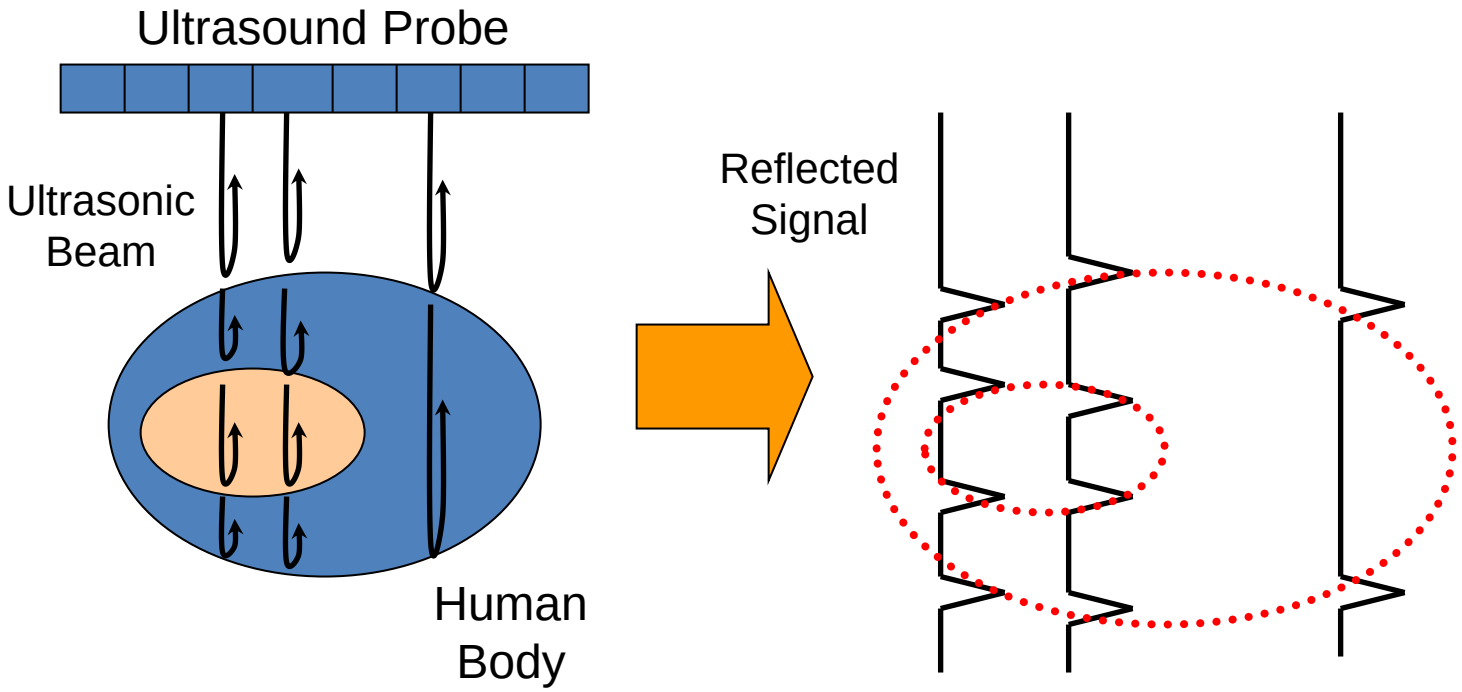
Ultrasound-based fingerprint/vein recognition



Ultrasonic transducer array

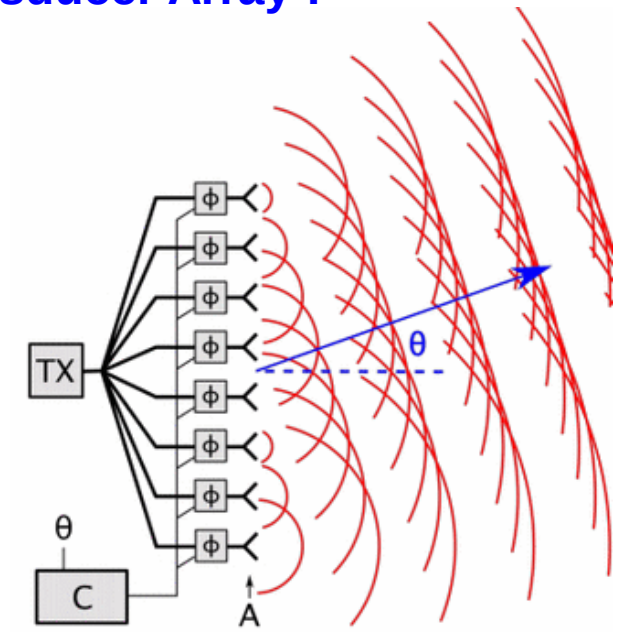
- Similar to medical imaging
- Not affected by sweat or dirt
- Convenient
- Small, low-power consumption
- 3 dimensional recognition
- Fingerprint/vein/blood flow

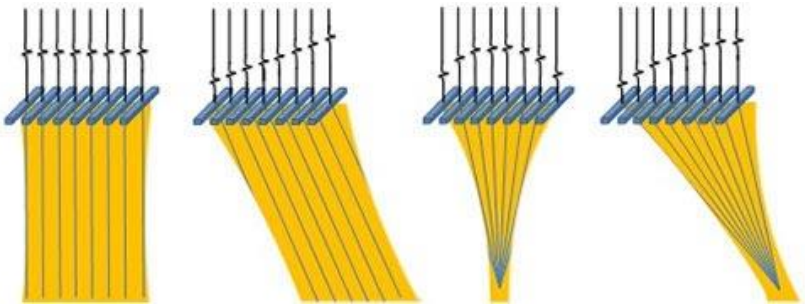
Principle of ultrasound imaging

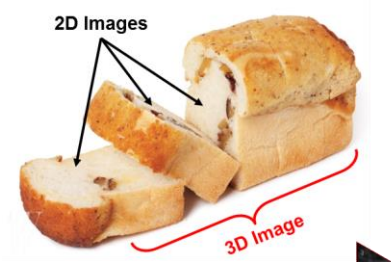


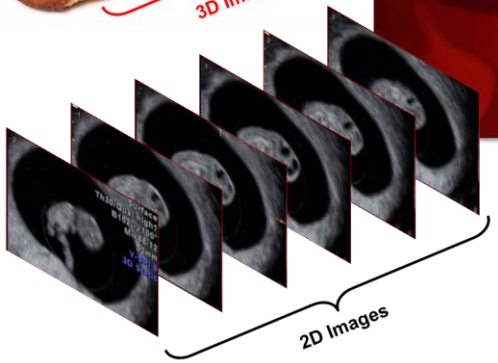
Beam-forming for 3D imaging

2D Transducer Array !



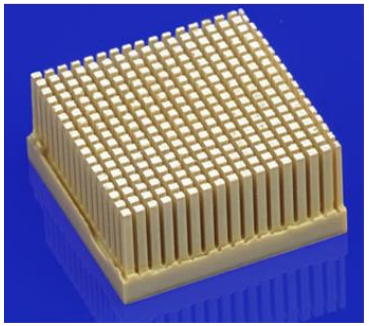






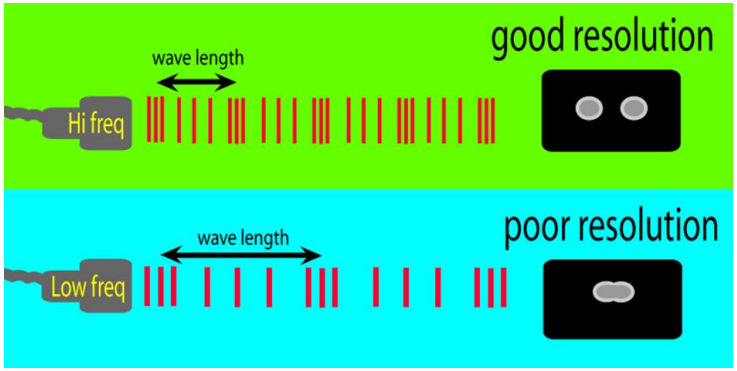
Issues on 2D array with bulk piezoelectric materials

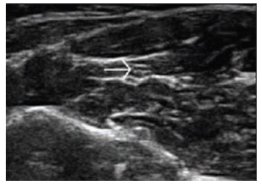
Wiring issue

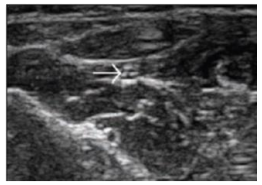


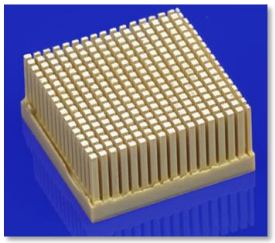
2D Arrays

Not scalable

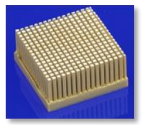








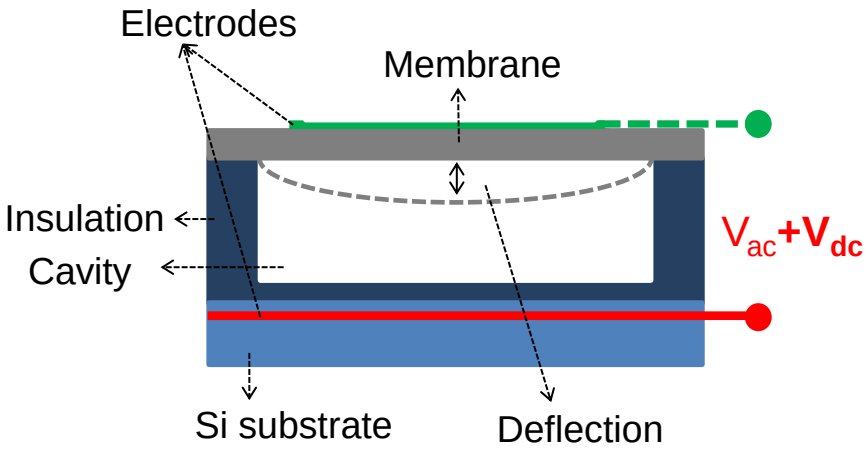
Lower Freq. Transducer



Higher Freq. Transducer

Micro-Machined Transducer (MUT)

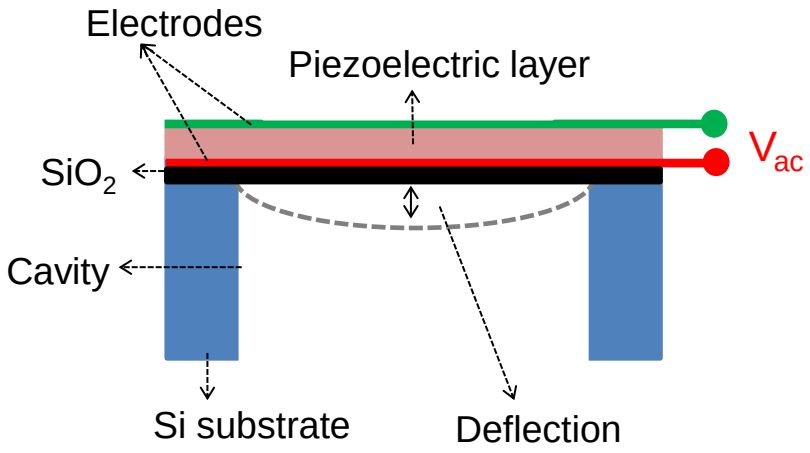
cMUT



Electrostatically-driven

- **Hard to fabricate**
- **High DC-field (electric shock!)**
- **Electrical charging**
- **Non-linear behavior**

pMUT

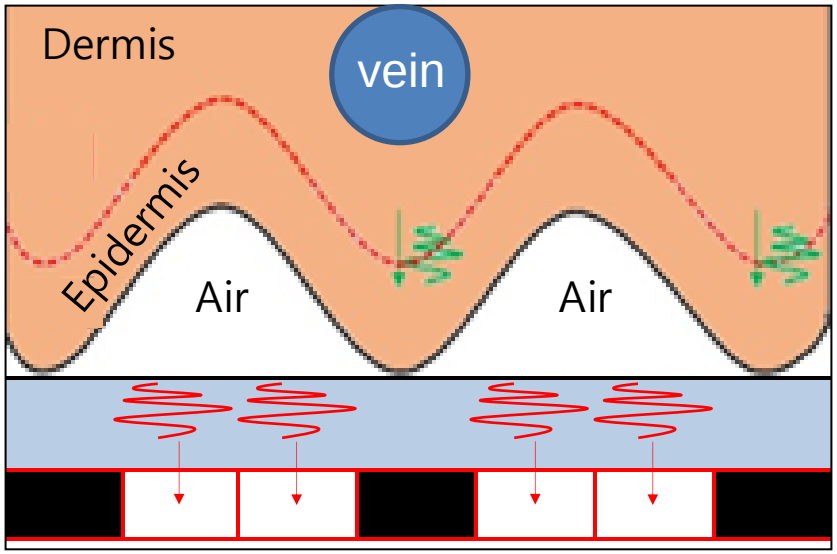


Piezoelectrically-driven

- **Relatively easy to fabricate**
- **No DC-field necessary**
- **Stable**
- **Linear behavior**

pMUT-based fingerprint/vein imaging system

Vein recognition without gel !



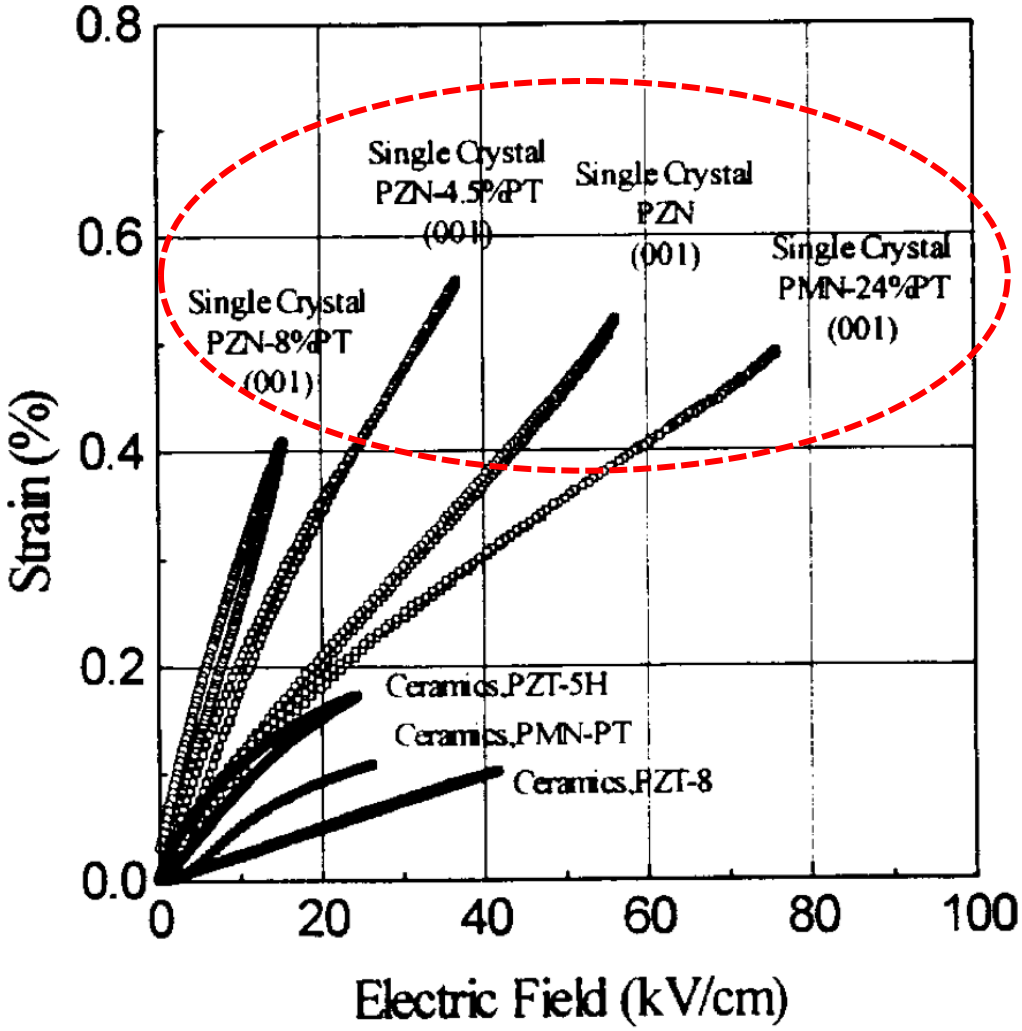
Ultrasonic transducer array

vs.

<gel for impedance matching>

Giant piezoelectric relaxor-ferroelectrics

$Pb(Mg_{1/3}Nb_{2/3})O_3$ - $PbTiO_3$ Single Crystals



- **Giant piezoelectric material.**

PMN-PT Single crystal is 10 times higher than PZT ceramic.

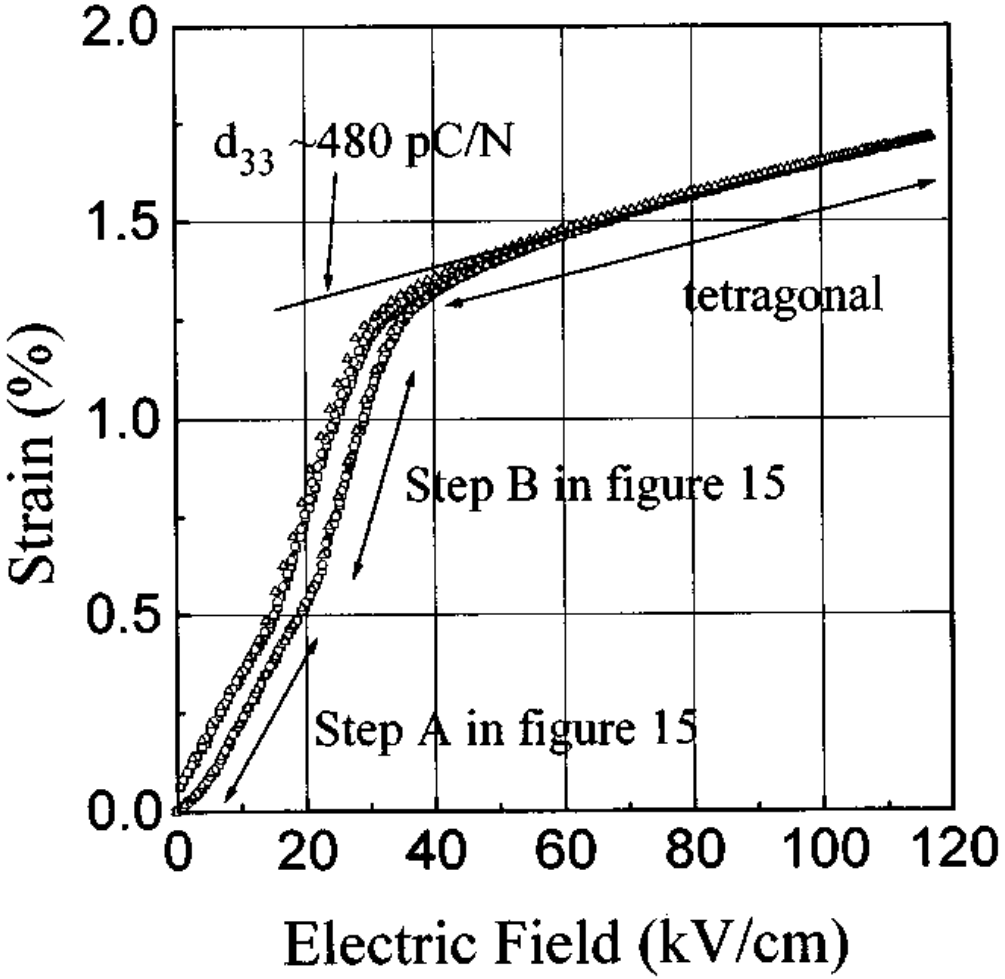
(d_{33}= ~2000 pC/N, k_{33}= ~0.92)

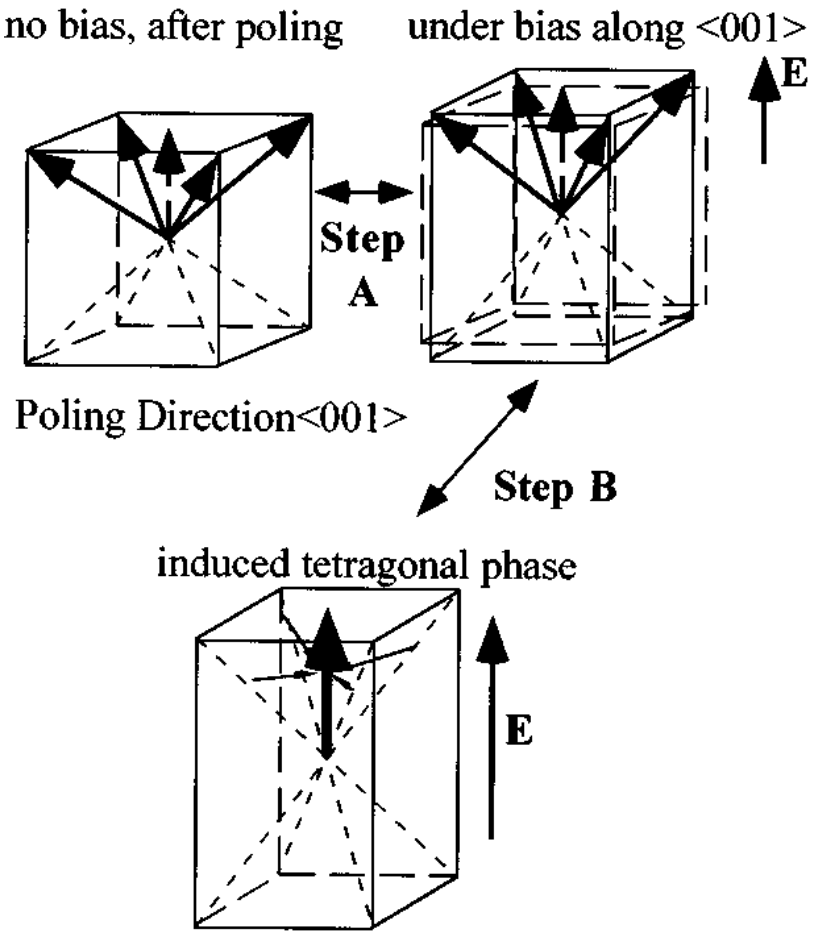
S-E. Park, T.R. Shrout , J. Appl. Phys. 82, 1804 (1997).

Giant piezoelectric relaxor-ferroelectrics

> 1.7% strain

Field-Induced Phase Transition in (001) PZN-8% PT Single Crystal

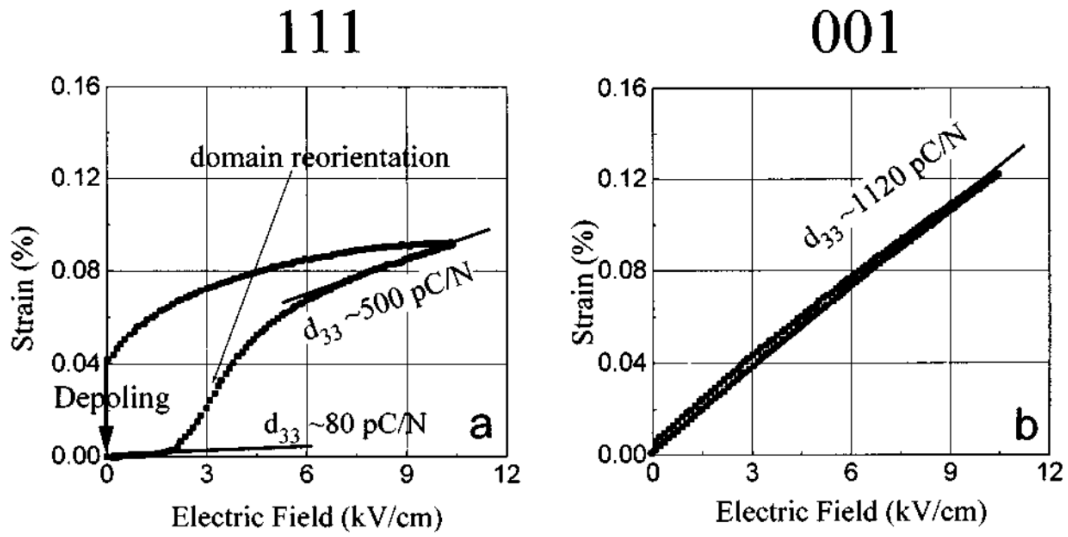




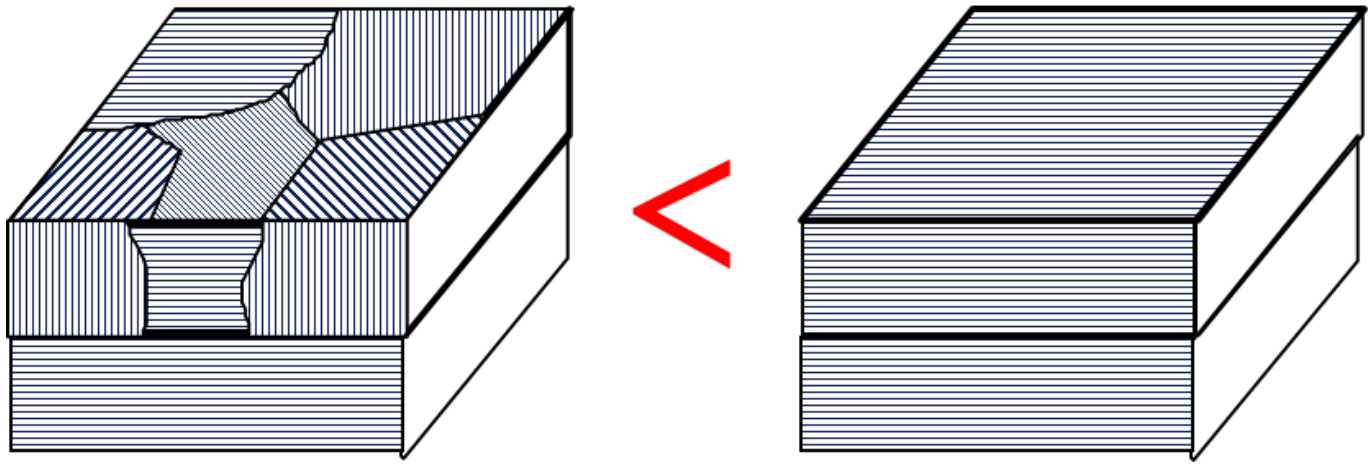
S-E. Park, T.R. Shrout , J. Appl. Phys. 82, 1804 (1997).

Giant piezoelectric relaxor-ferroelectrics

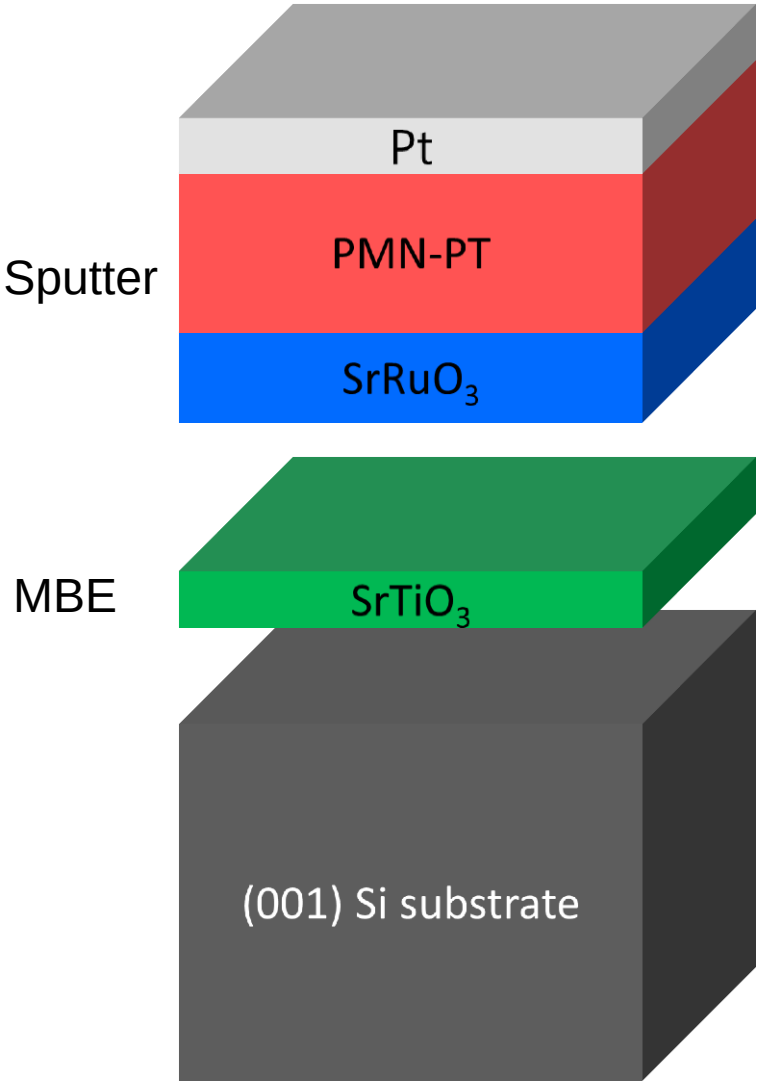
- **Anisotropic piezo-property:** d_{33} [001] > d_{33} [111]

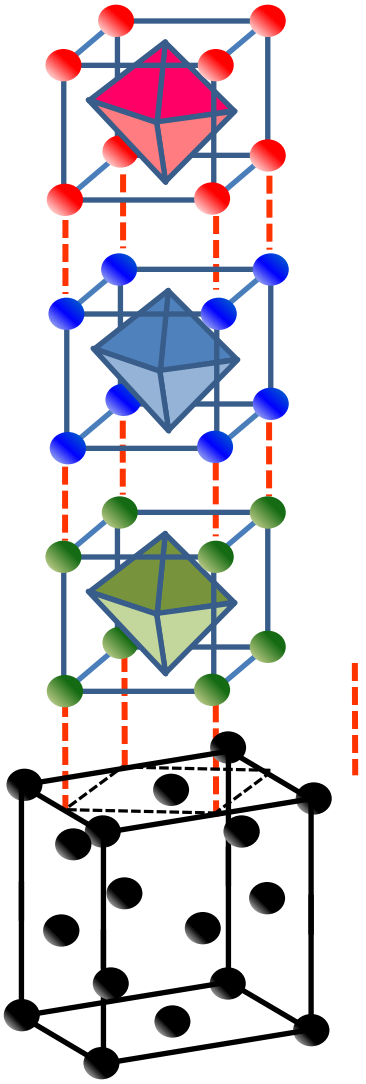


Polycrystalline **(001) Epitaxial**



Epitaxial PMN-PT thin films on Si





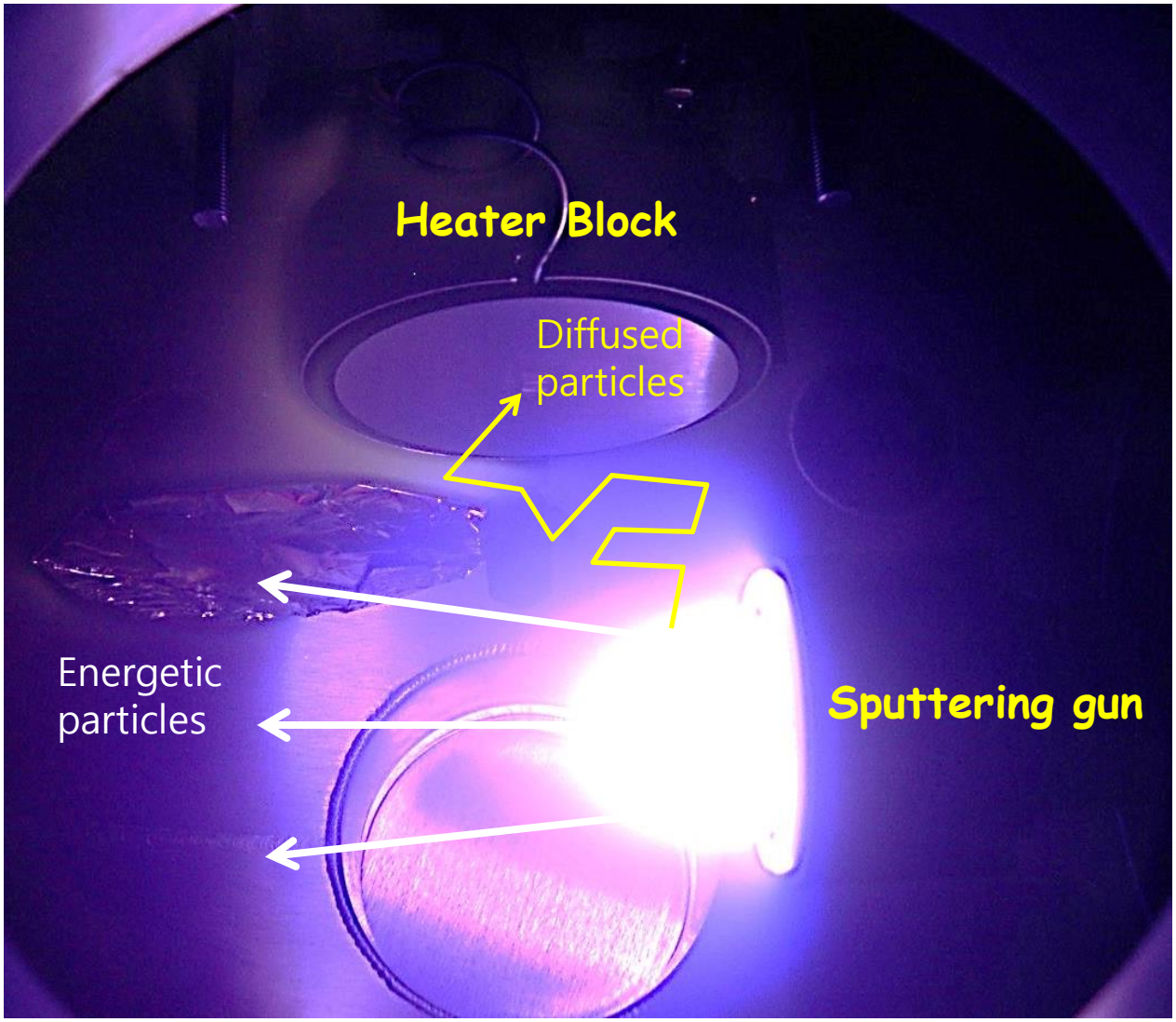
Piezoelectric material
Perovskite structure
~4.02 Å

Conducting oxide
Perovskite structure
~3.930 Å

Insulating oxide
Perovskite structure
3.905 Å

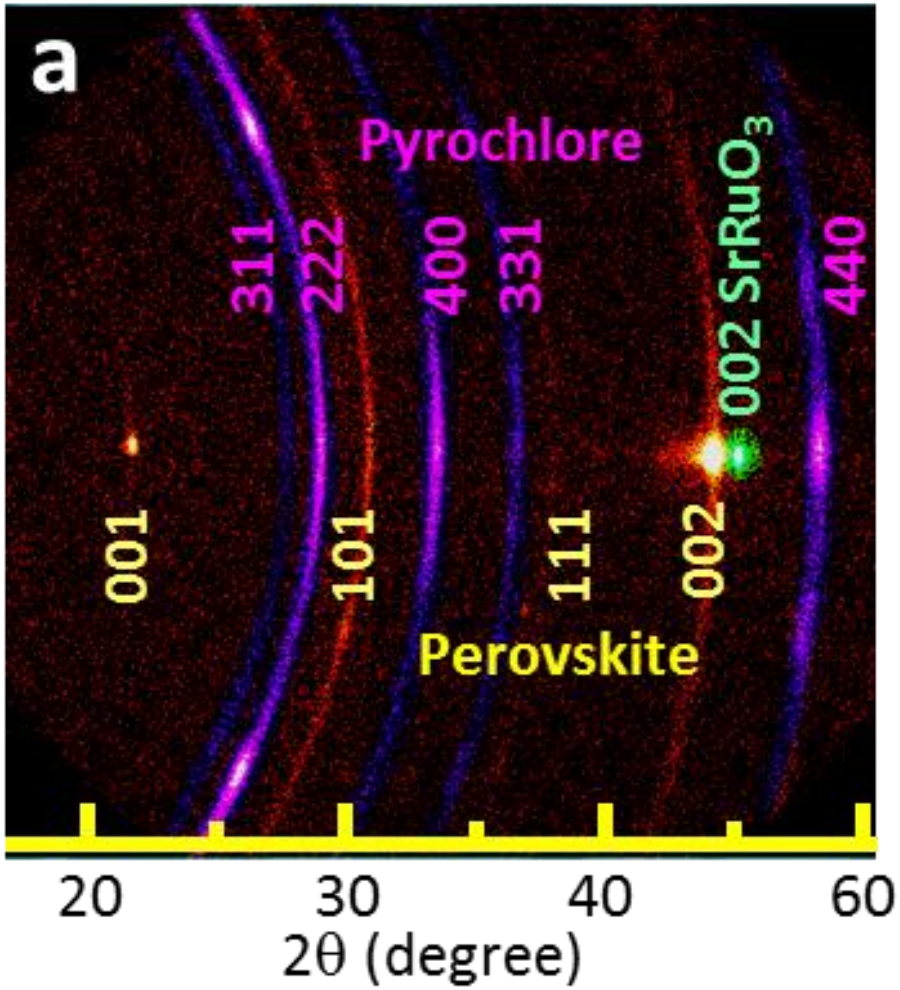
Si substrate
Diamond Cubic structure
Lattice parameter: 5.4302 Å

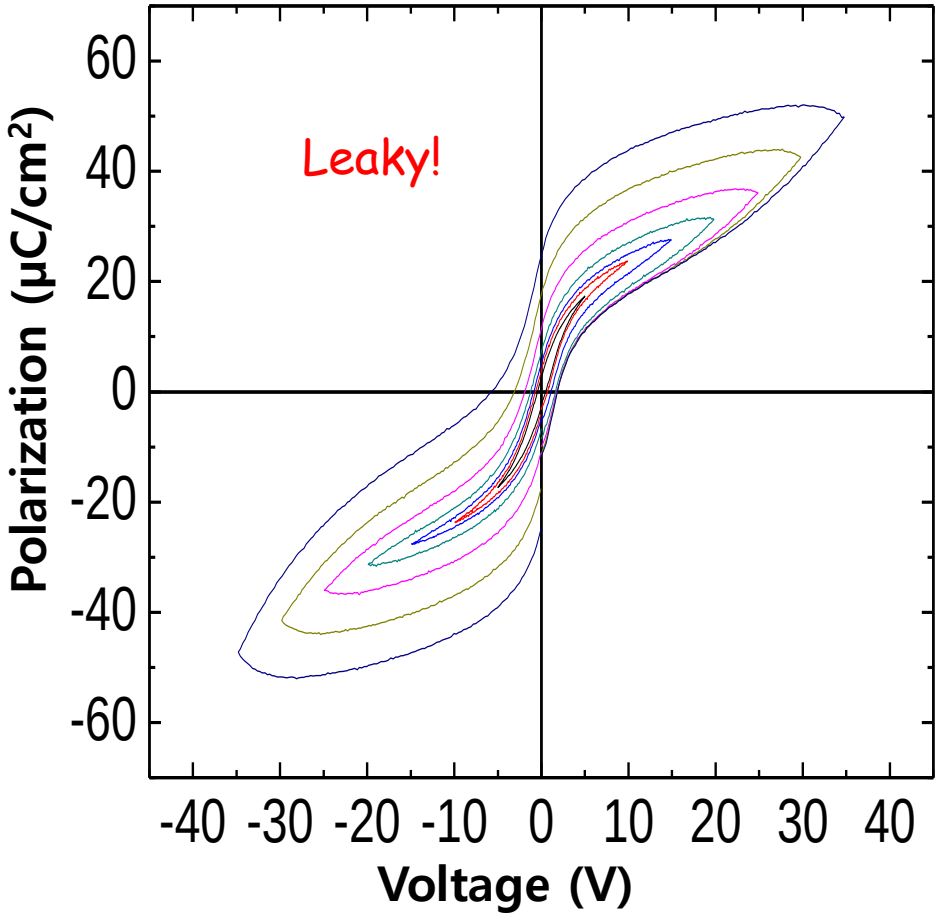
Off-Axis Sputtering for high-quality films



Challenge for PMN-PT film growth

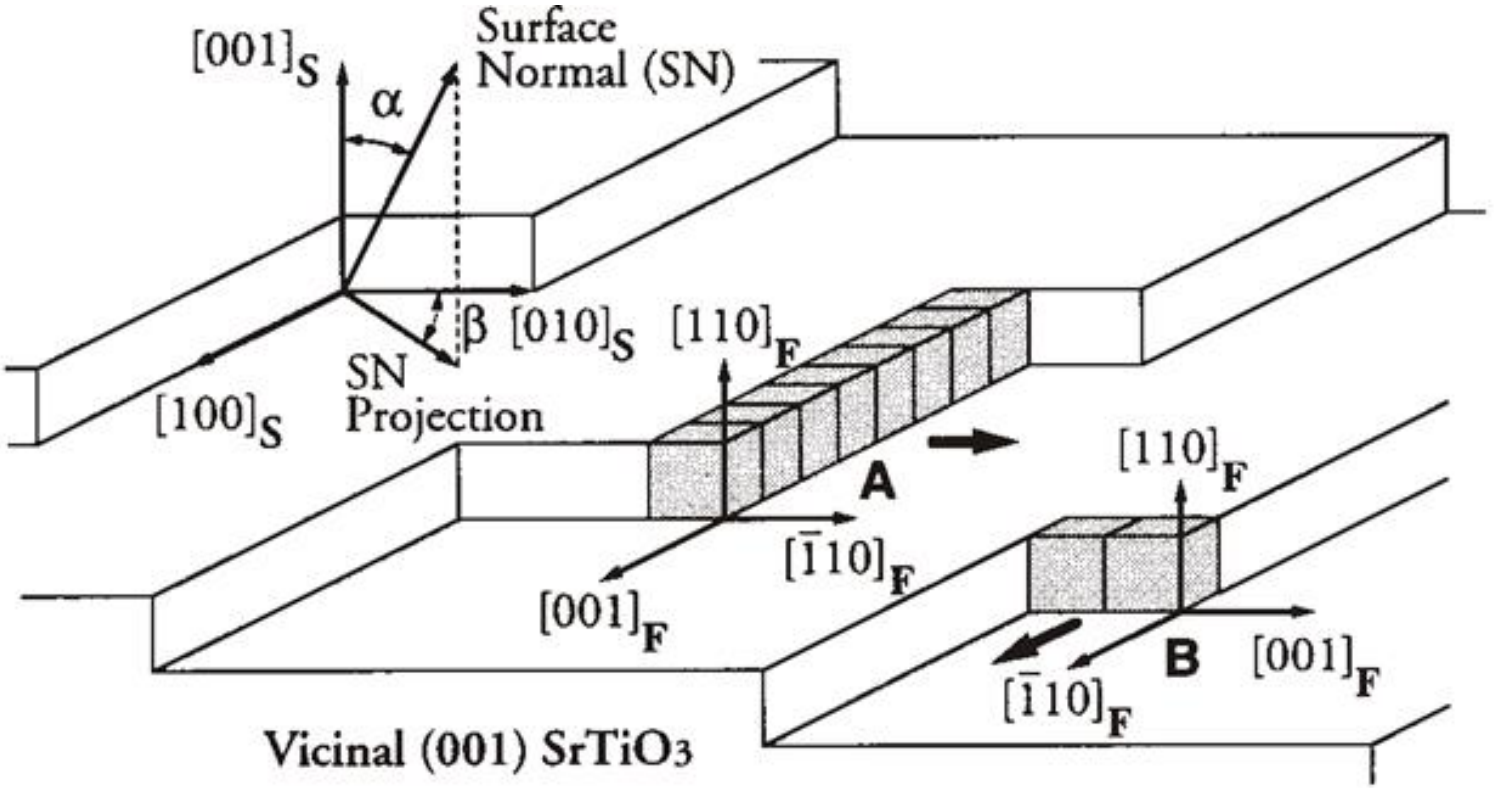
Volatile PbO



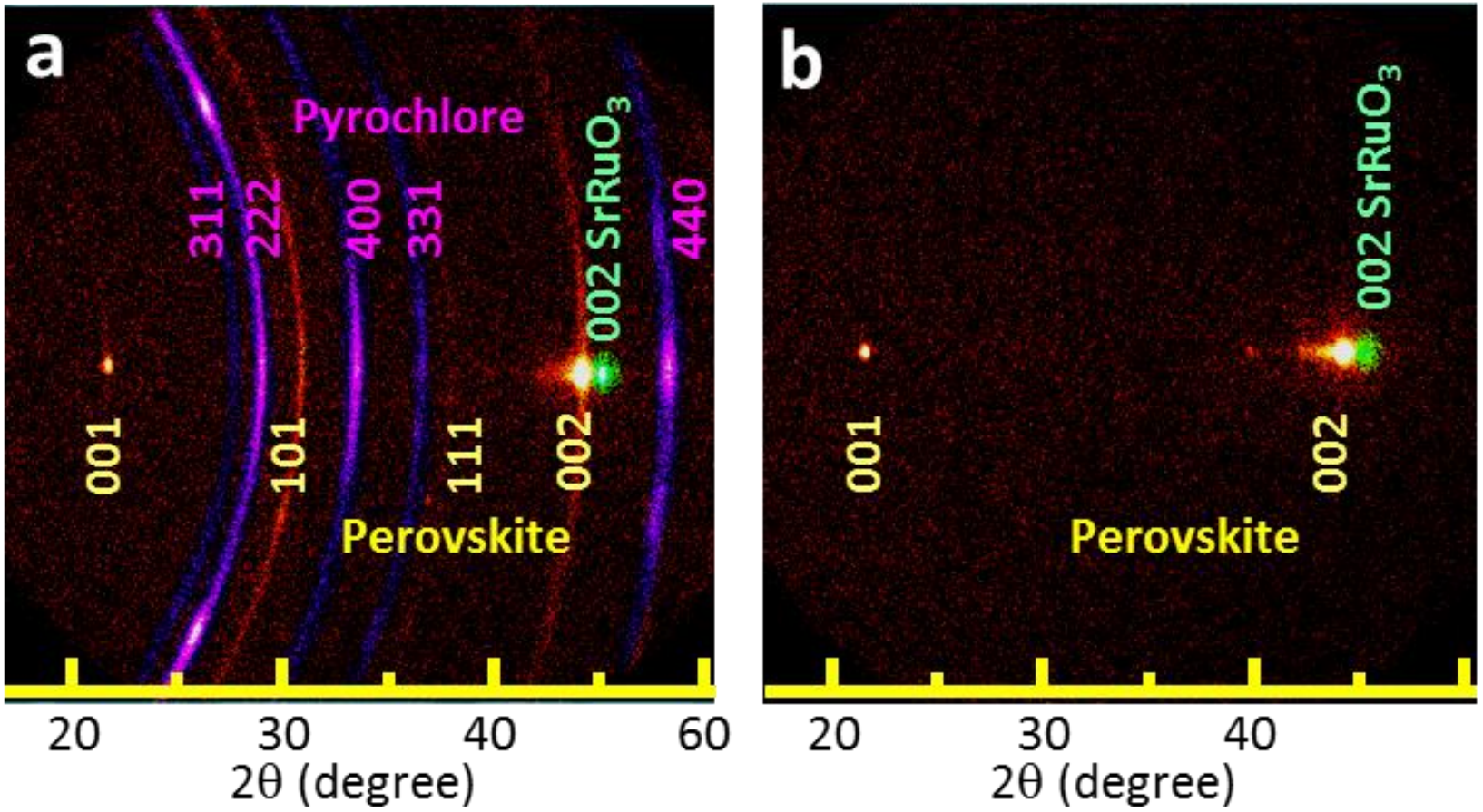


Miscut substrate to fix volatile PbO

Step as a preferential nucleation site



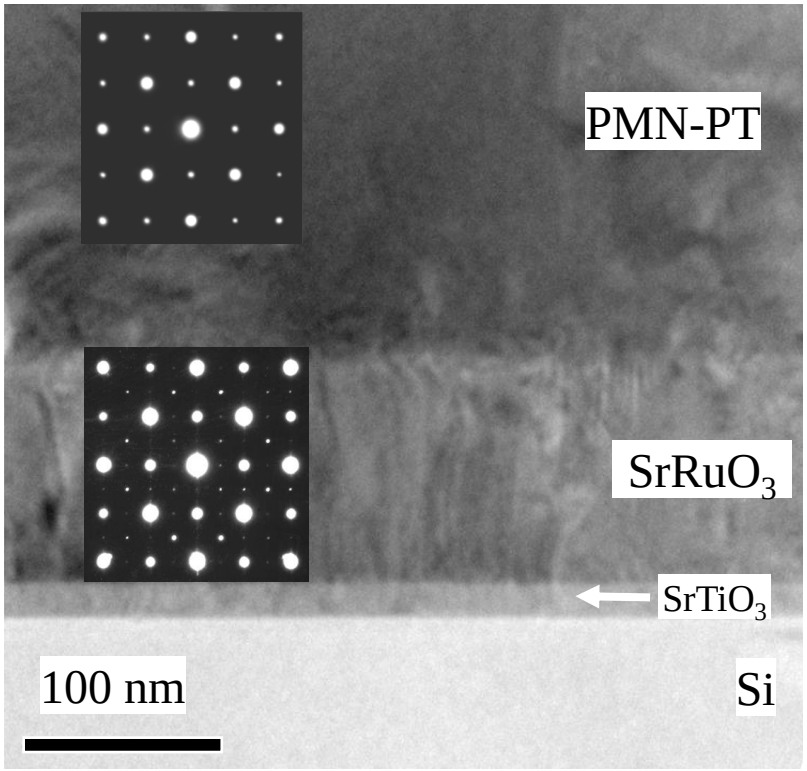
X-ray diffraction with 2D area detector for PMN-PT /$SrRuO_3$/Si

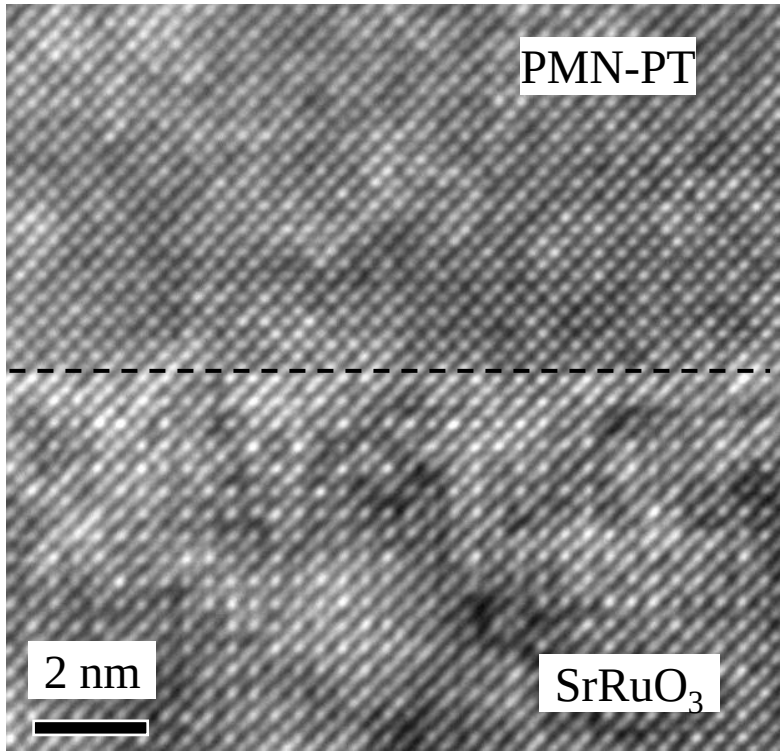


Exact (001) Si

4° miscut (001) Si

Cross Sectional TEM images of PMN-PT on silicon





Rocking Curve FWHM

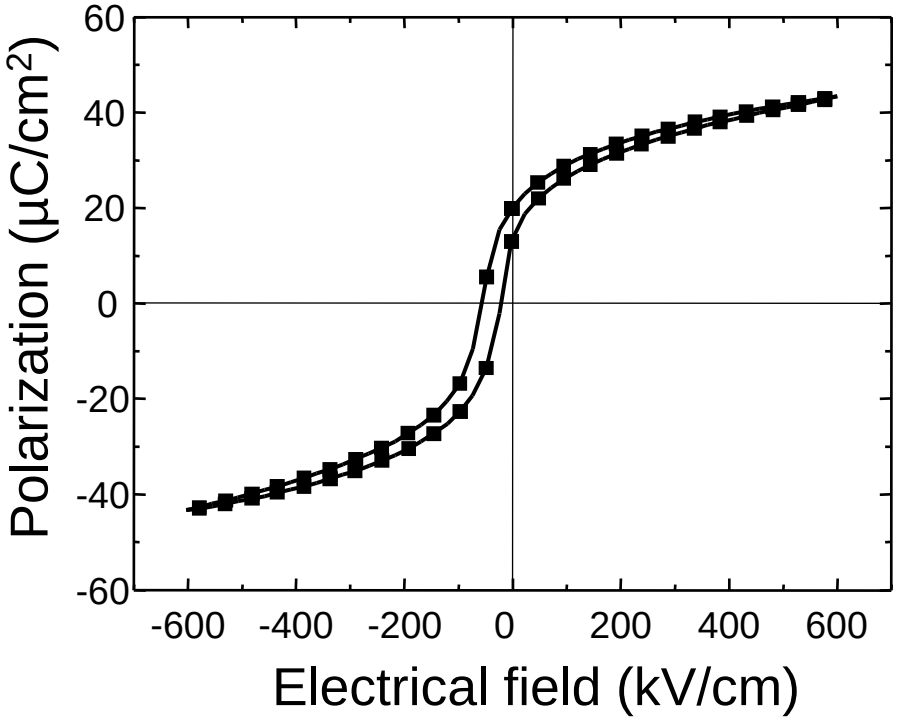
0.23°

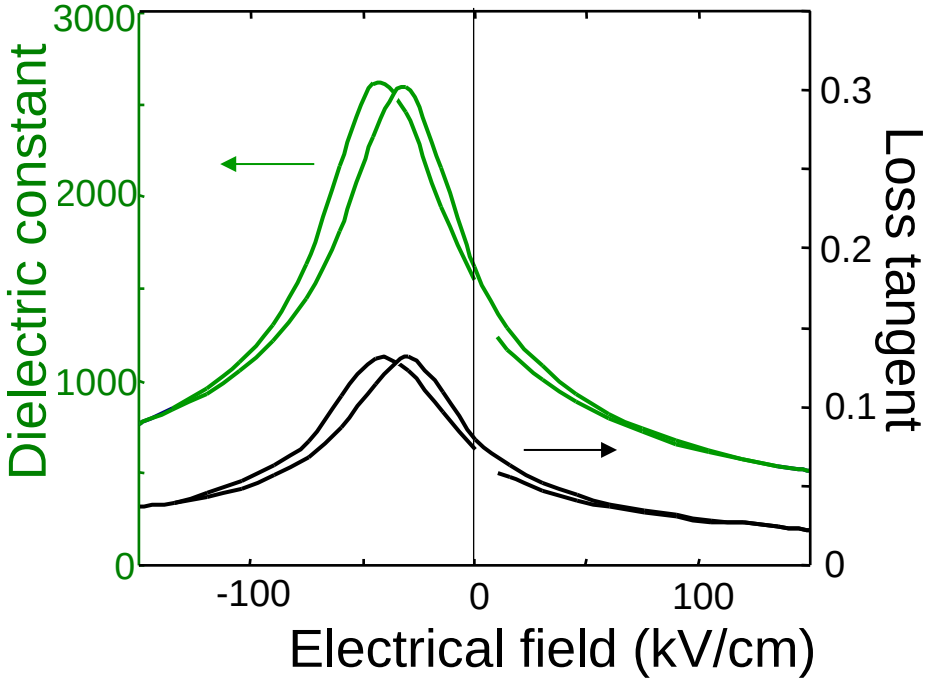
0.58°

TEM by X.Q. Pan, Michigan

0.32° (bulk PMN-PT single crystal)

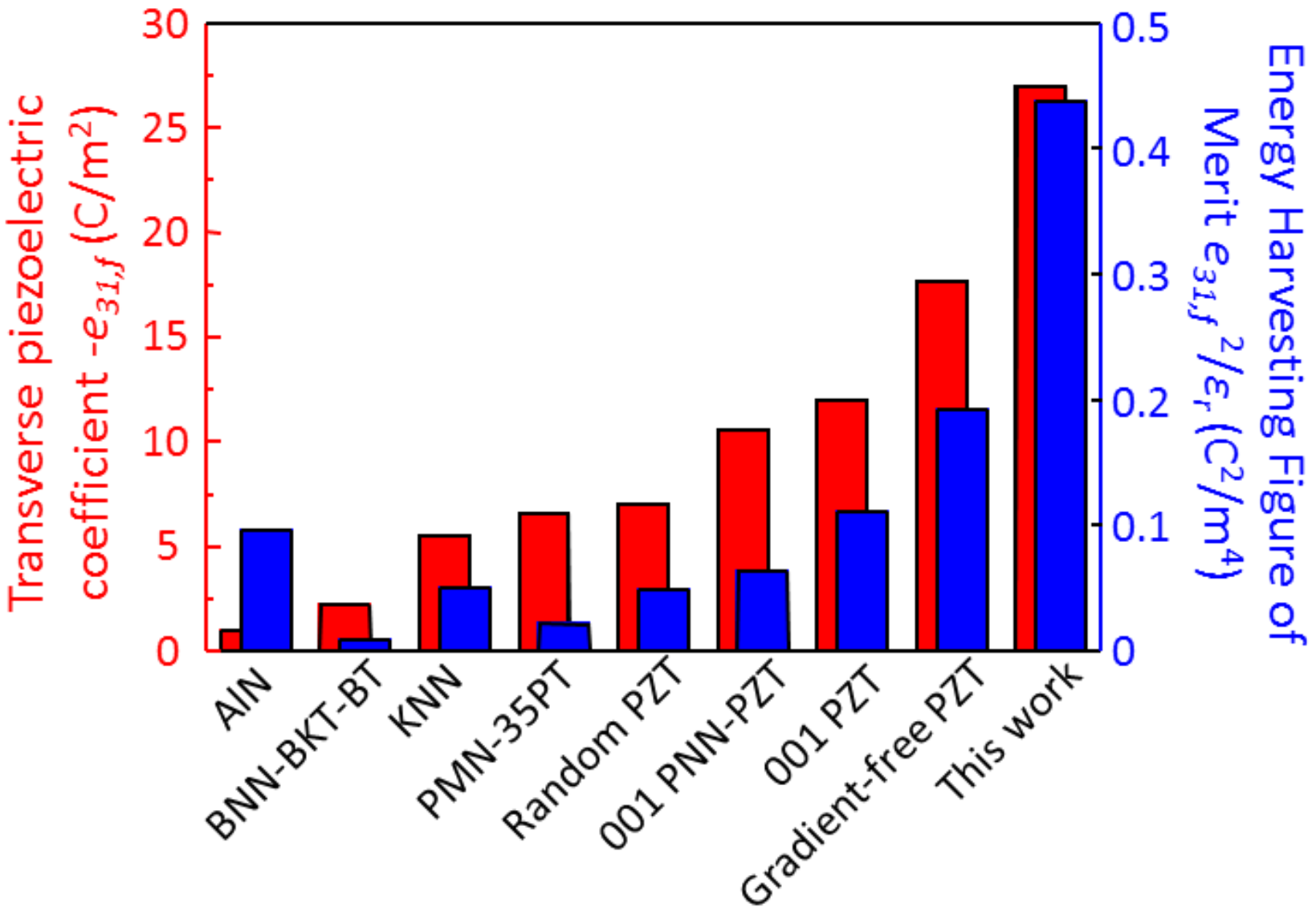
Strong Imprint- Unipolar Operation





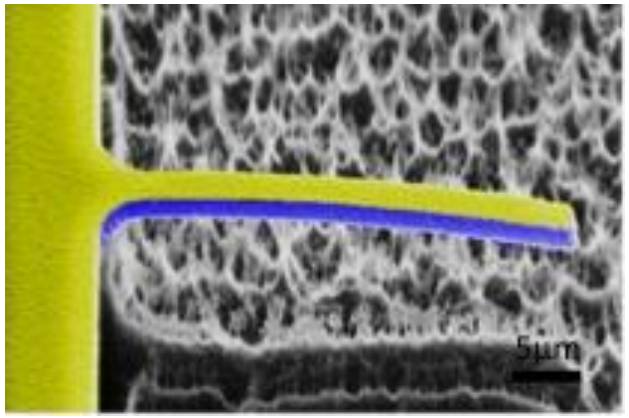
- **Highly insulating (>600 kV/cm)**
- **Strong imprint: unipolar operation**
- **Reduced dielectric constant for better detection**

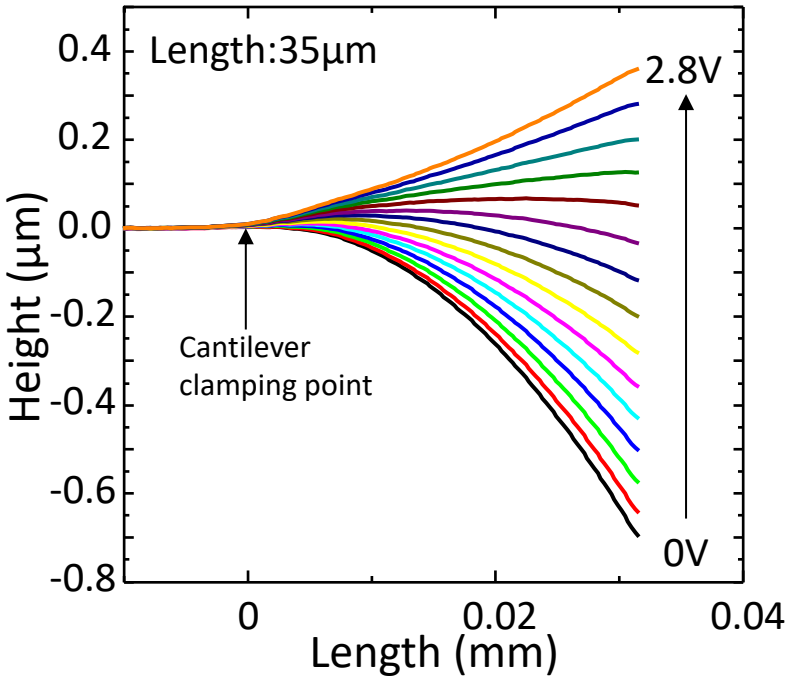
Piezoelectric and energy harvesting FOM



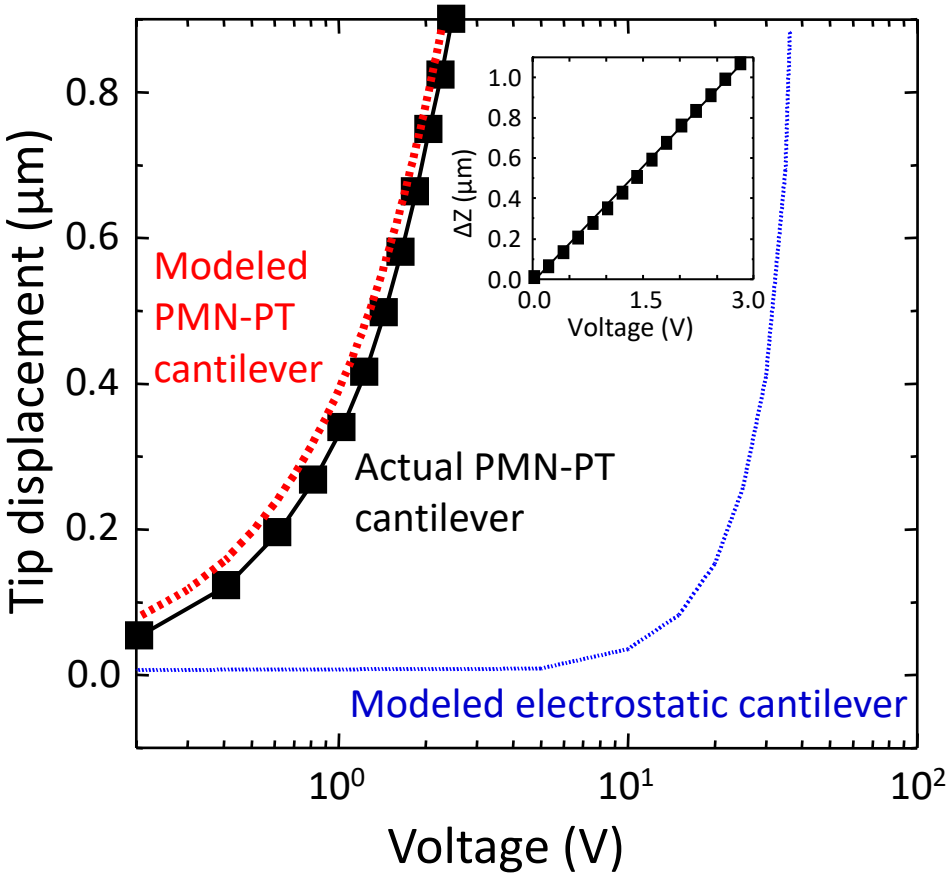
MEMS performance

- Simulations match experimental data using bulk PMN-PT parameters.
- PMN-PT piezoelectric properties unaffected by processing.





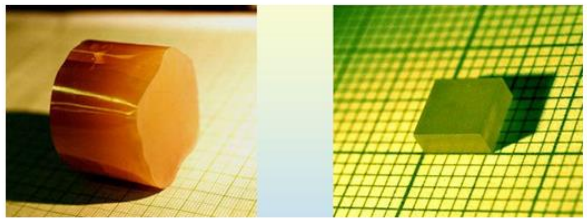
0.375 μm / V deflection



S.H. Baek et al. Science 334, 958 (2011)

Development of relaxor-ferroelectrics

Gen.	Material	T_C(℃)	T_{RT} (℃)	d_{33} (pC/N)	k_{33}	Q_m	E_c (kV/cm)
1st	PMN-0.29PT	135	96	1700	0.91	150	2.3
2nd	PIN-PMN-PT	191	125	1500	0.92	180	5.0
	PMN-PZT	210	113	1750	0.92	150	5.0
3rd	Mn:PMN-PT	~150		~1200		95~450	3.8
4th	Mn:PMN-PZT	203	141	1140	0.92	1050	6.3



1st generation

· High d_{33}, k_{33}

· Low T_C, T_{RT}, E_c, Q_m

2nd generation

· High d_{33}, k_{33}, T_C, T_{RT}, E_c

· Low Q_m

3rd generation

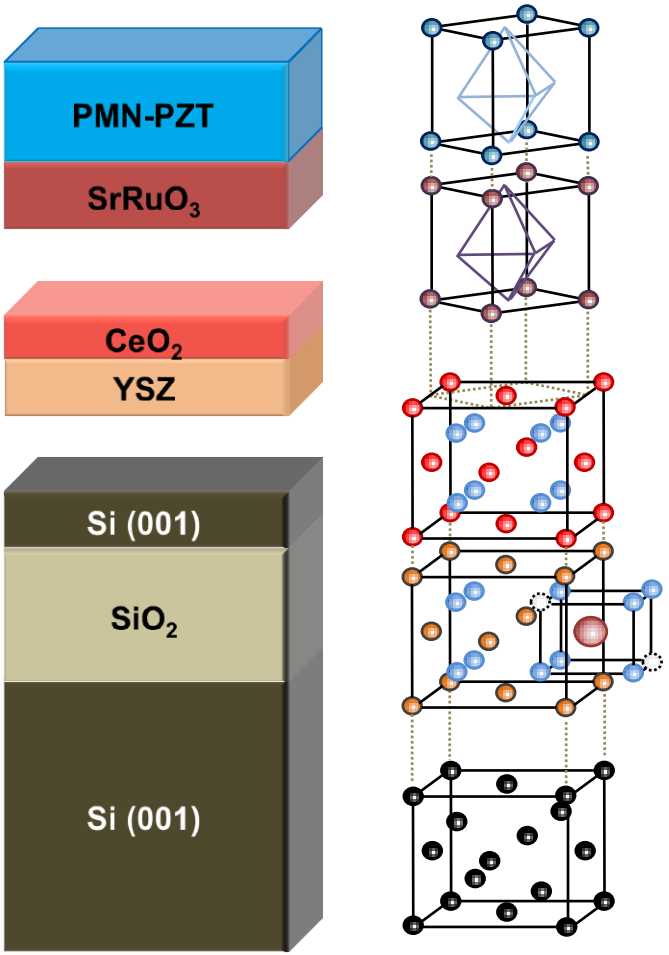
· High d_{33}, k_{33}, Q_m

· Low T_C, T_{RT}, E_c

4th generation

· High d_{33}, k_{33}, T_C, T_{RT}, E_c, Q_m

PMN-PZT heterostructure on SOI



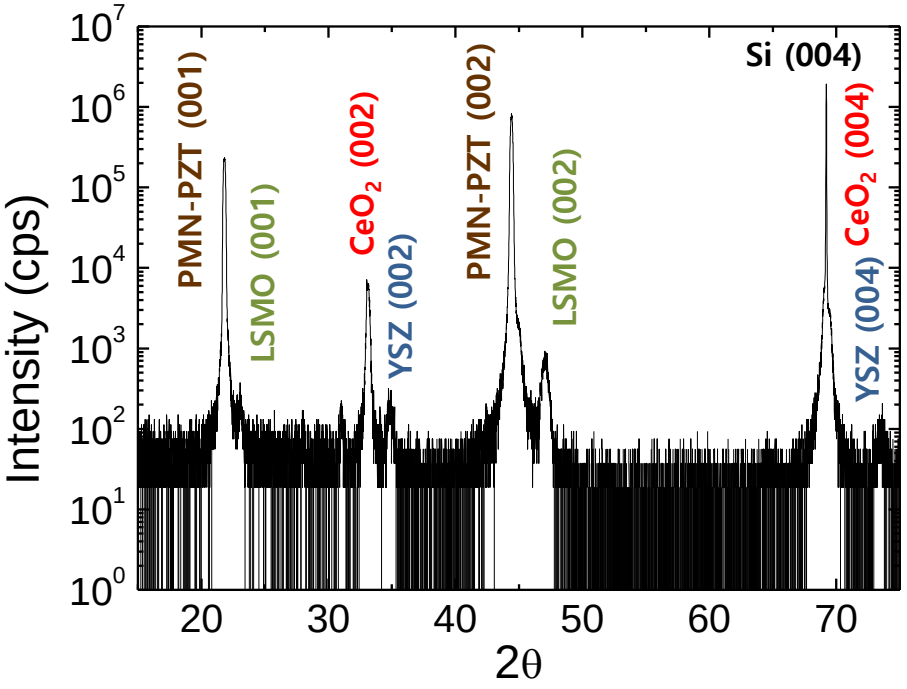
1. Mn: $Pb(Mg_{1/3}Nb_{2/3})O_3$-$Pb(Zr,Ti)O_3$

- *Giant piezoelectricity &*
- *high temperature field stability*

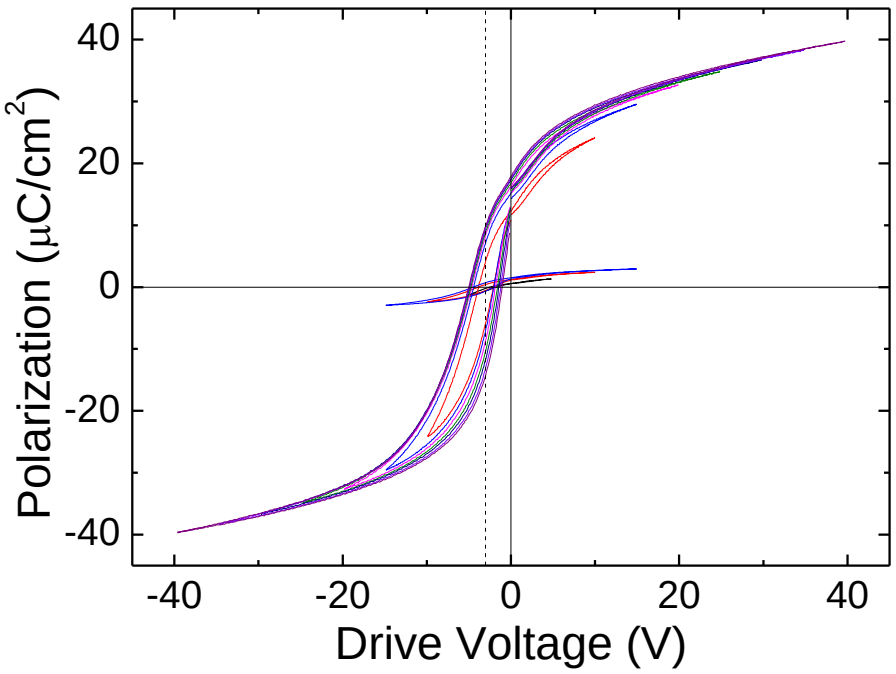
2. All sputtering process

1 μm PMN-PZT/LSMO/CeO_2/YSZ/Si

XRD



P – E Curve

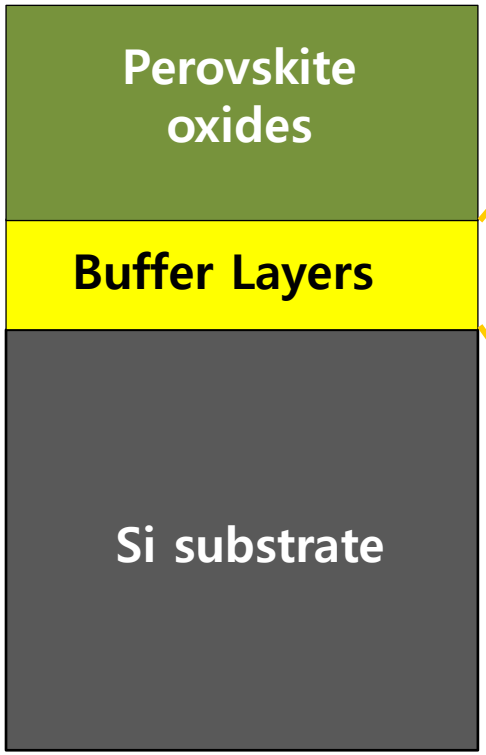


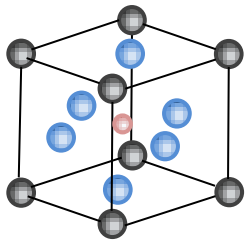
Summary

- **We have fabricated epitaxial PMN-PT piezoelectric heterostructures on silicon with unparalleled piezoelectric properties. (d_{33}: 1200 pm/V and e_{31}: -29 C/m^2)**
  (2-3 times better than best piezoelectric films ever reported and on Si !)

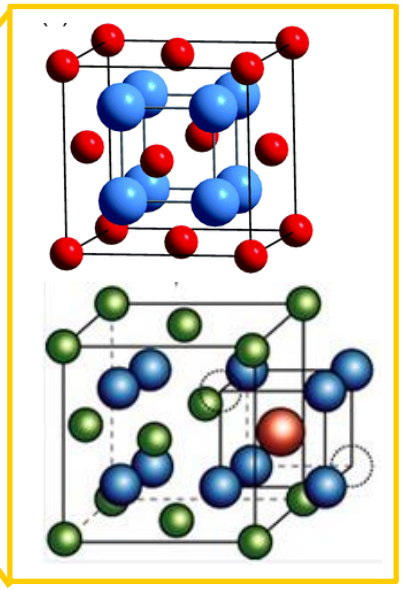
- **High strain piezoelectric heterostructures on silicon can be used for integrated MEMS devices for actuation, sensing and imaging**
  - **High frequency ultrasound transducer 2-D arrays**
  - **Hyper-Active NEMS**
  - **High frequency filters**
  - **Energy Harvesting**

Buffer layer for epitaxial Oxide on Si



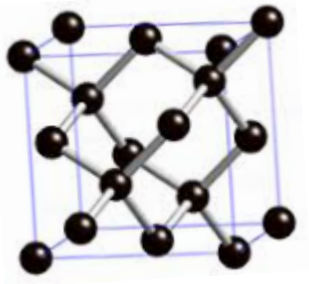


SRO, LSMO, PZT
3.86~3.93 Å



CeO_2
5.41 Å

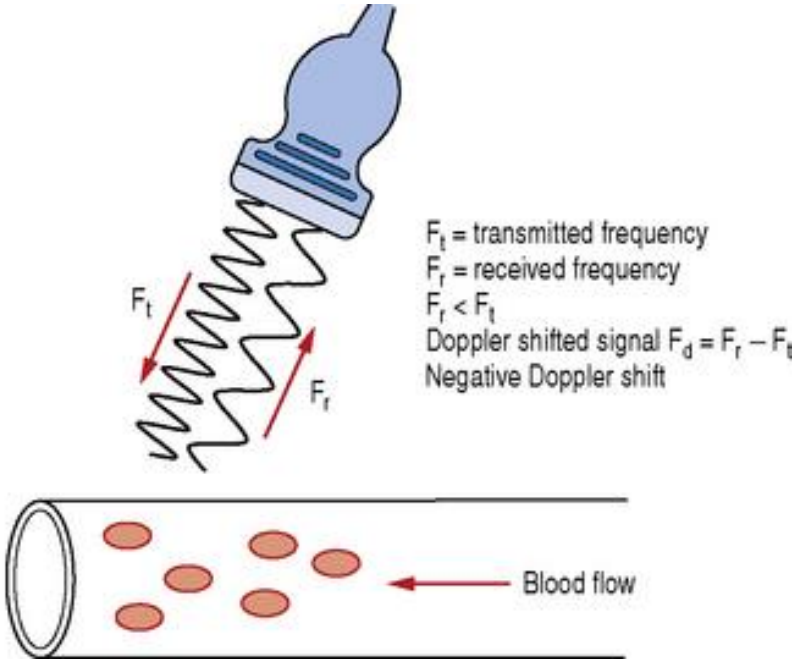
YSZ
5.15 Å

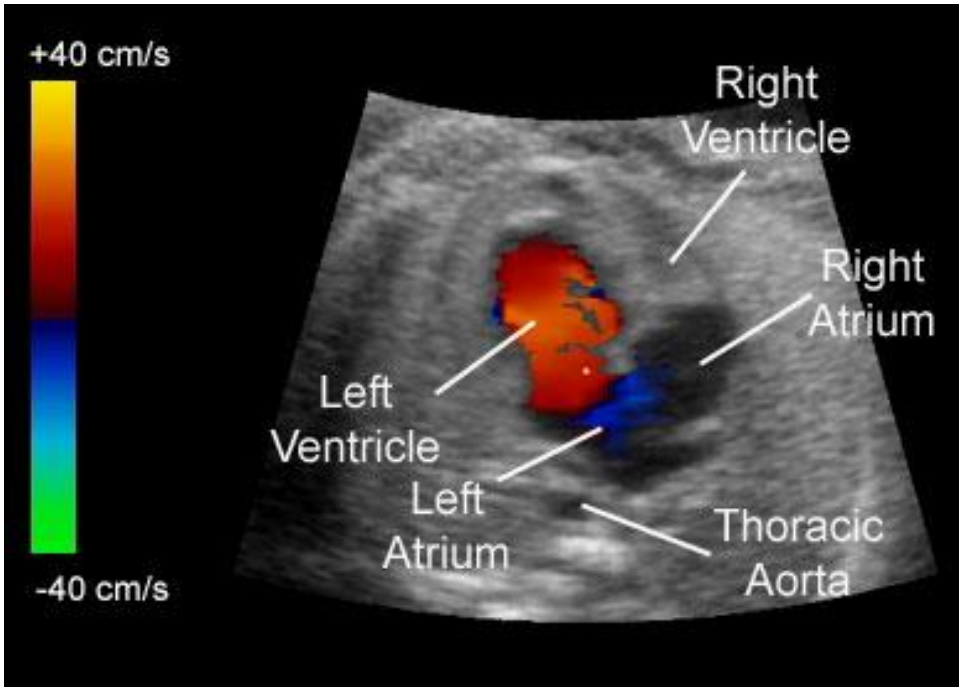


Si
5.43 Å

Principle of ultrasound imaging

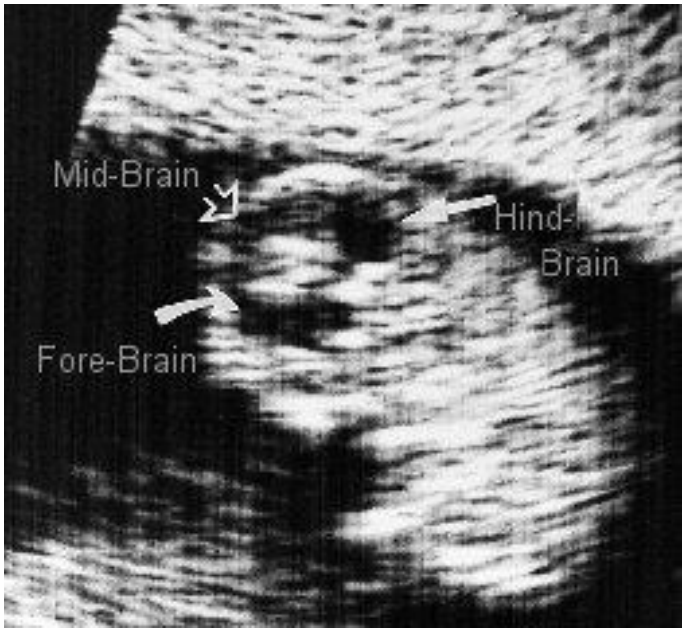
Doppler effect for blood flow imaging



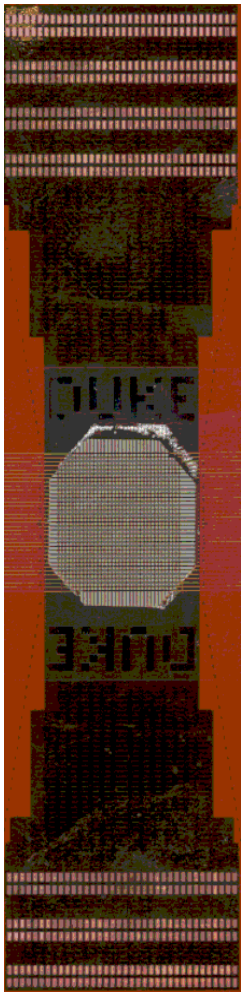


의료용 초음파 이미징 기술

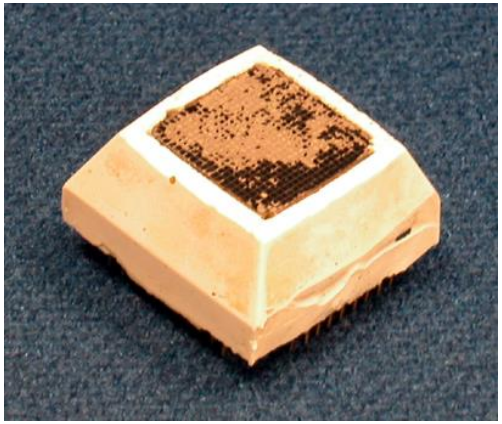
(1960)

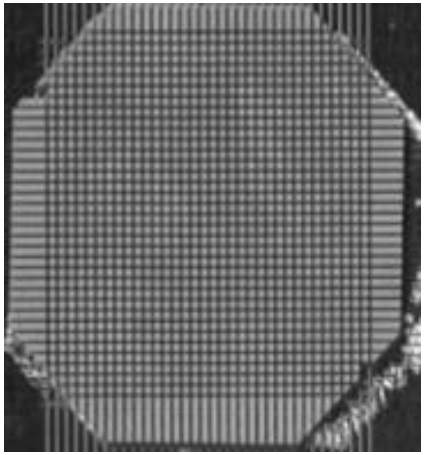


(2003)
Ceramic PZT
transducer array
At 1 MHz



20x20
first 2-D array
(currently
256x256 = 65,536
subdiced elements)





S.W. Smith, Duke Univ.