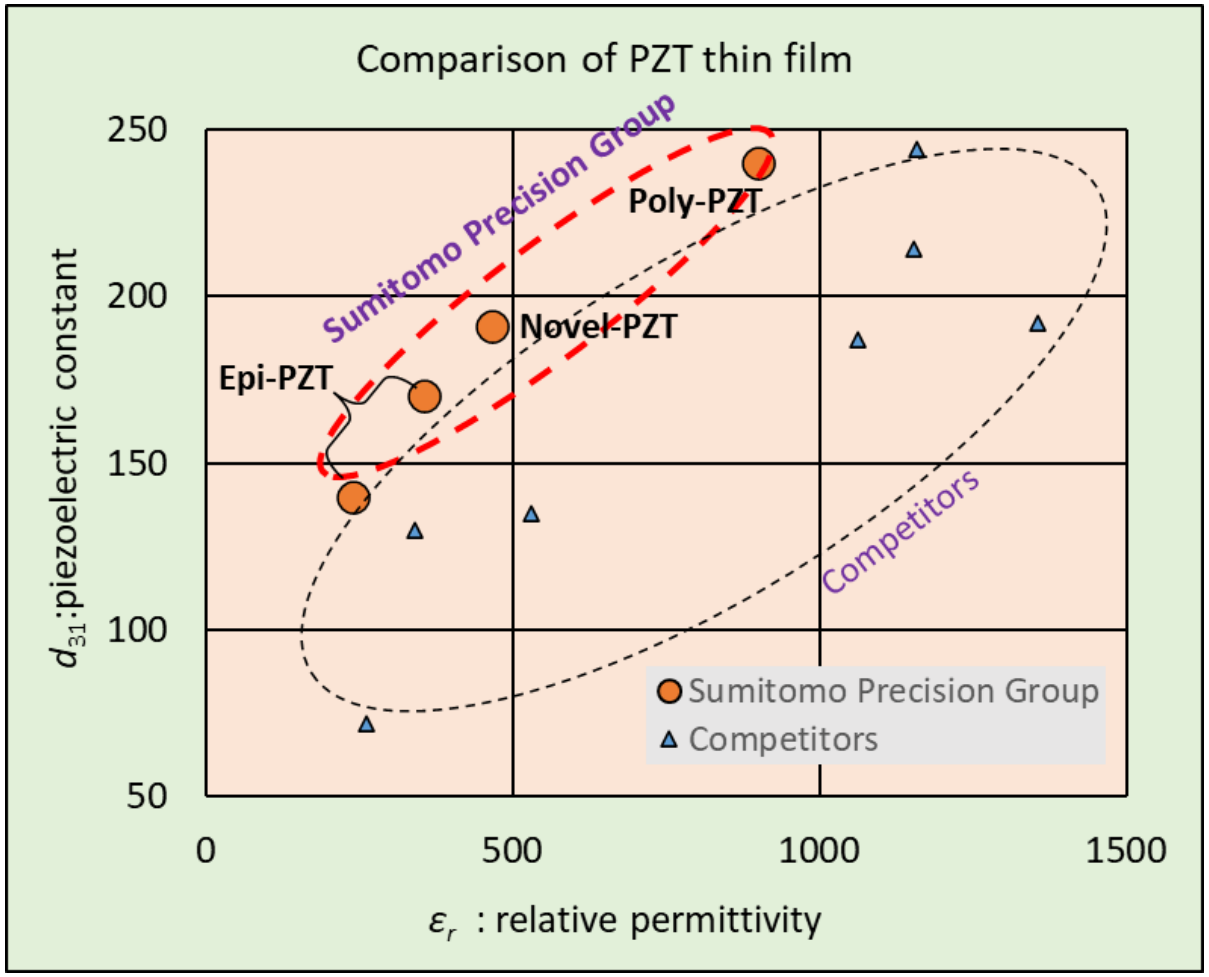
PZT thin film line-ups for MEMS devices

MEMS∞
Sumitomo Precision Products Co.,Ltd.

MPM24-019

PZT Line-ups

- Sumitomo Precision Group has PZT thin film line-ups having higher d_{31} and lower ε_r.
- Our Poly-PZT has high FOM (Act-FOM) for actuators.
- Our Epi-PZT has high FOM (Tr-FOM) for transducers (i.e., emitting and receiving device).
- Our Novel-PZT has intermediate feature between Poly-PZT and Epi-PZT.



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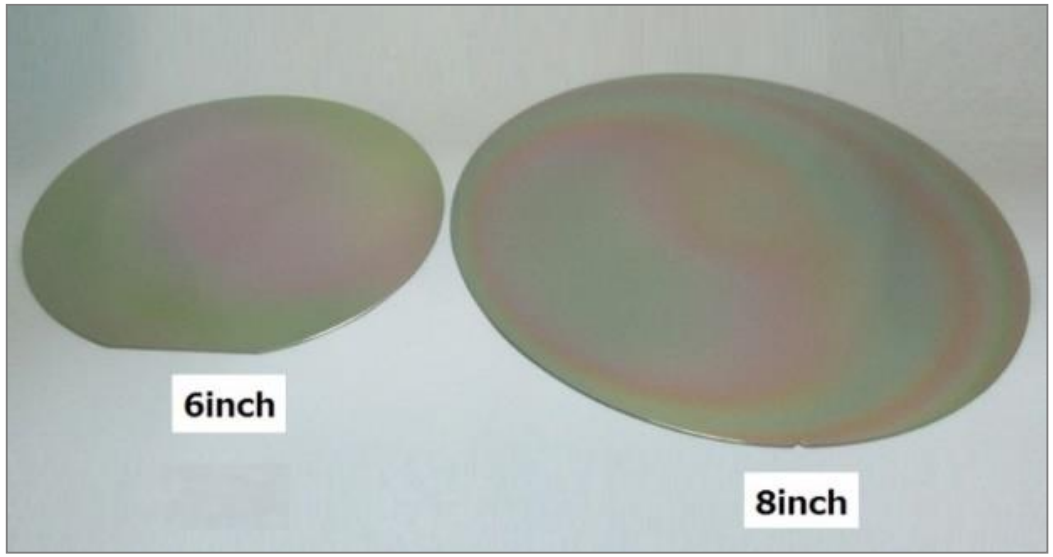
PZT Line-ups

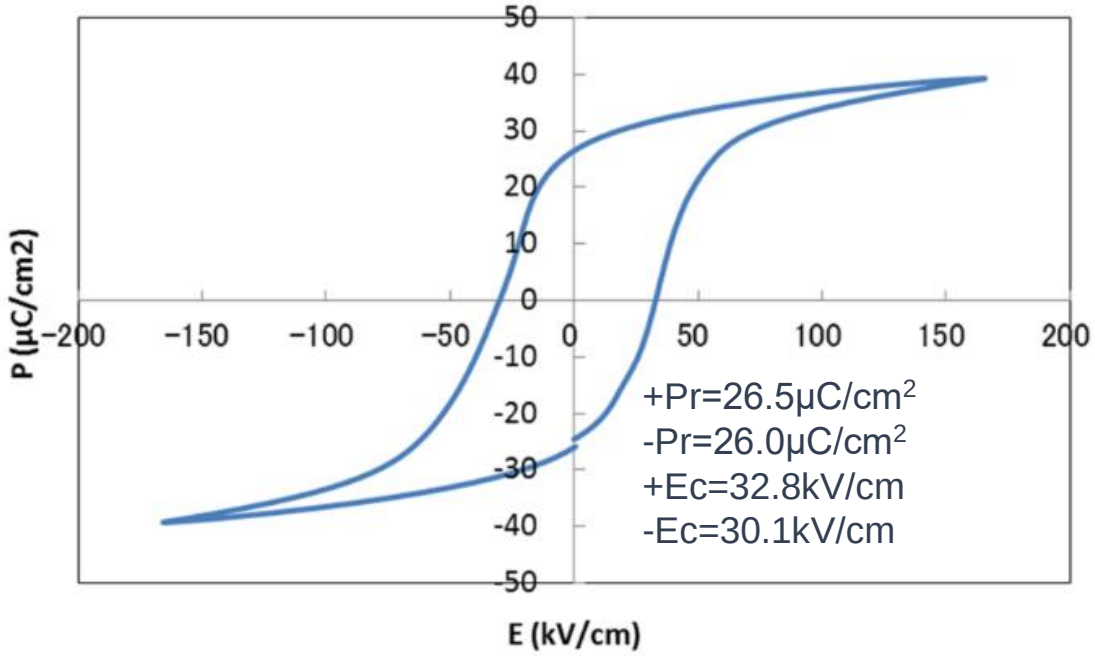
Type	Novel-PZT	Epi-PZT		Poly-PZT
PZT composition	MPB	Ti-rich	MPB	MPB
ε_r	465	239	354	900
Act-FOM (=-d_{31})	191 pm/V	140 pm/V	170 pm/V	240 pm/V
(=-$e_{31,f}$)	14.3 C/m^2	10.4C/m^2	12.7C/m^2	17.9 C/m^2
Tr-FOM ($\propto (d_{31}^2)/\varepsilon_r$)	50 GPa	52 GPa	52 GPa	40 GPa
tanδ	<0.03	<0.03		<0.03
Stress (tensile)	89 MPa	200 MPa		30 MPa
Wafer type	Bulk Si or SOI	Bulk Si or SOI		Bulk Si or SOI
Wafer size	6” or 8”	6” or 8”		6” or 8”
PZT thickness	2 μm	2 μm		1~5 μm

Poly-PZT

- High $-d_{31}$ (Act-FOM), suitable for actuators.
- Lower stress enables us to deposit 5 um film on 8” wafers.
- Commercially available.



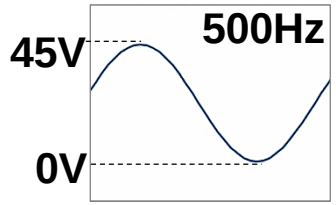
P-E hysteresis loop

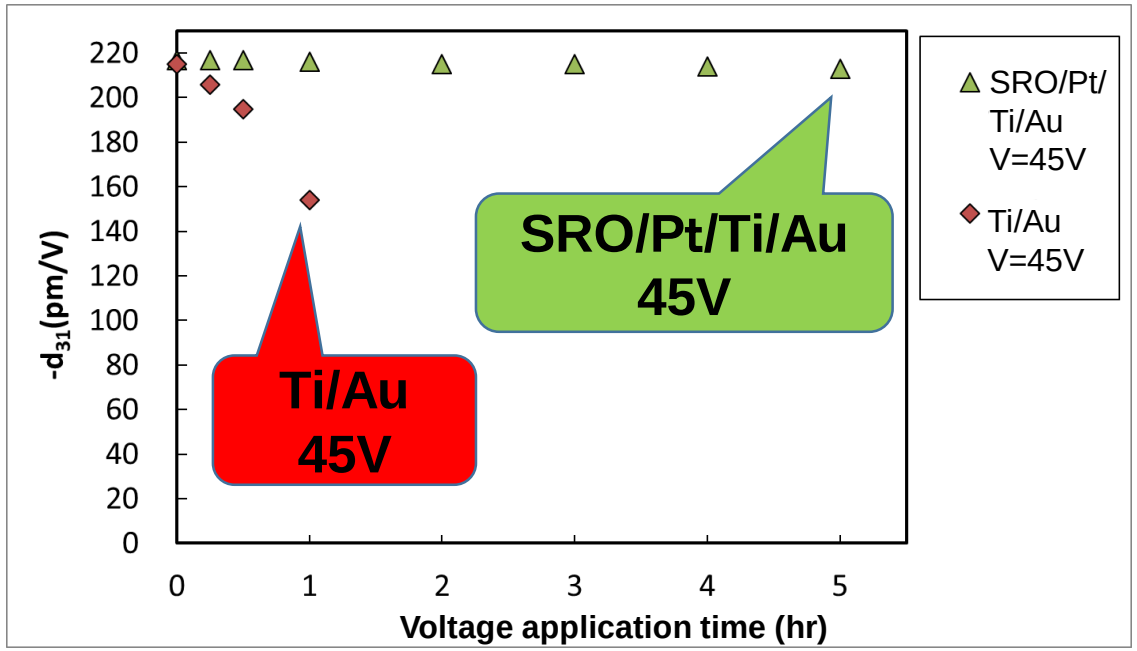


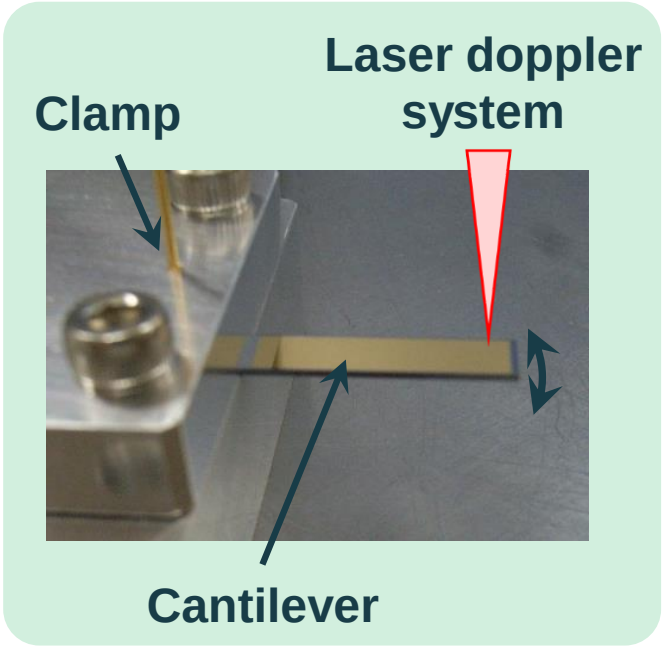
Poly-PZT : Reliability Improvement　SRO in Top Electrode

SRO is effective for reliability improvement

Top electrode : SRO/Pt/Ti/Au and Ti/Au
Applied voltage : 0~45V sine wave/500Hz
Test sample : Cantilever (PZT thickness: 3μm)







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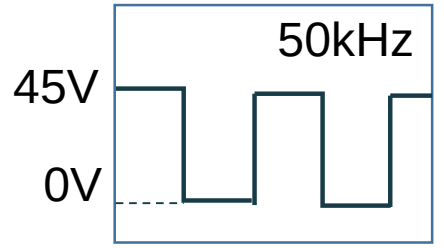
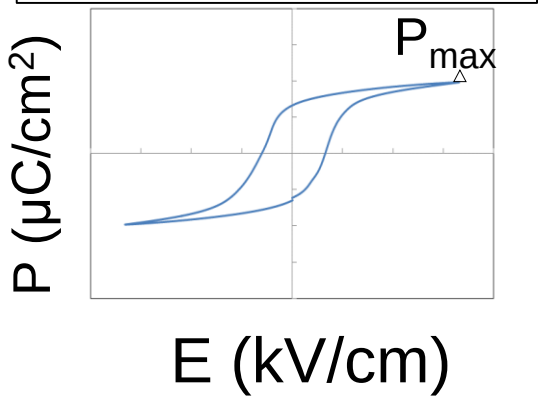
Poly-PZT : Reliability Improvement　SRO in Top Electrode

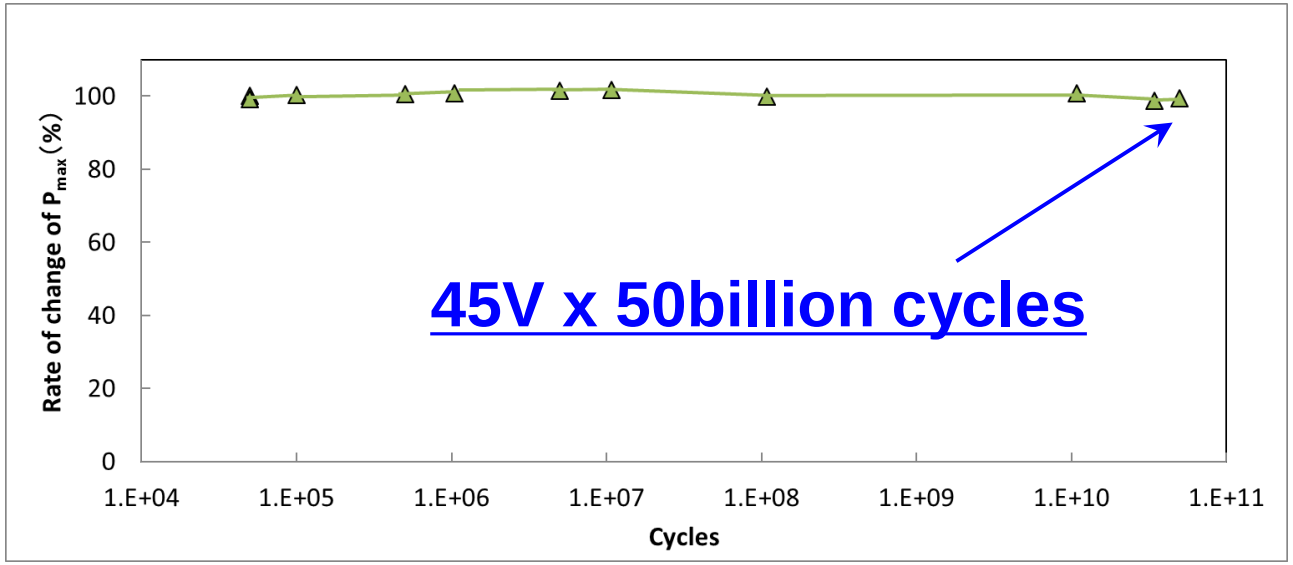
SRO is effective for reliability improvement

Top electrode : SRO/Pt/Ti/Au
Applied voltage : 0~45V, square wave, 50kHz
Test sample : TEG pattern, □300μm (PZT thickness: 3μm)



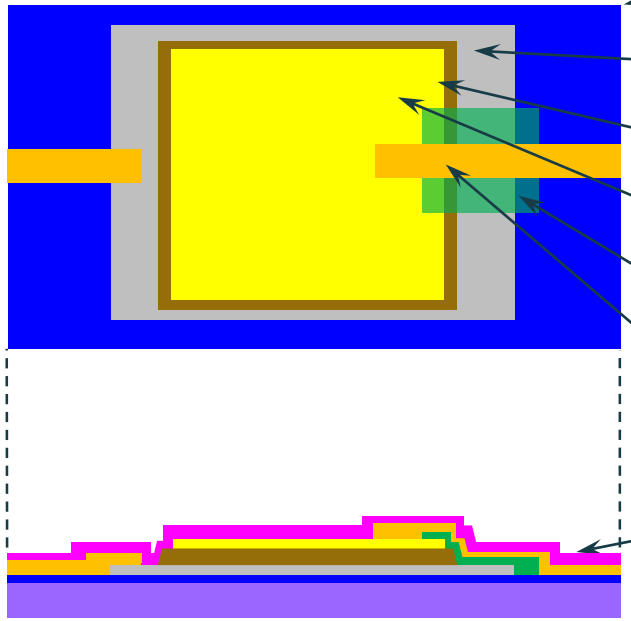
PE hysteresis loop





Poly-PZT : Reliability Improvement　Protection film

High-temperature and high-humidity bias test



Test sample

Thermal oxide
Bottom electrode (Ti/Pt/SRO)
PZT t=2μm
Top electrode (SRO/Pt)
Isolation layer
Metal tracking
Protection

1: No protection film
2: TEOS film
3: Alumina ALD film
4: Material x and y laminate ALD film
(ALD : Atomic layer deposition,
collaborated with ALD vendor)

Test condition

45deg.C /95%RH / DC40V and 60deg.C /95%RH / DC30V

Poly-PZT : Reliability Improvement　Protection film

Reliability of PZT MEMS devices will be improved by using protection film

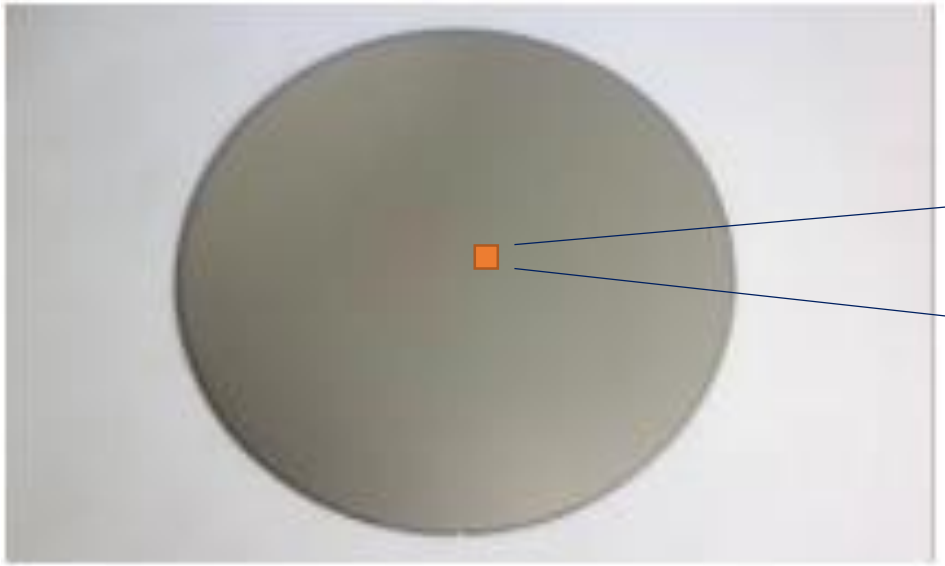
Failure criteria: > 1mA
Pattern area:0.013mm^2

	Without protection film	With 500nm PECVD TEOS	With 100nm ALD Al_2O_3	With 100nm ALD x/y laminate*
45deg.C 95%RH DC40V	< 2 hr	< 122 hr	> 160 hr	> 160 hr
60deg.C 95%RH DC30V	N/A	N/A	< 377 hr	> 2013 hr

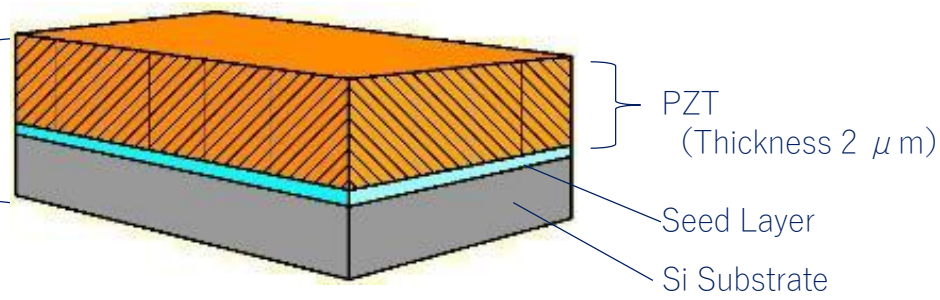
*** Laminate of material x and material y**

Epi-PZT

- Epi-PZT with Low-ε_r is targeting Transducers/Sensors applications.
- Samples available.



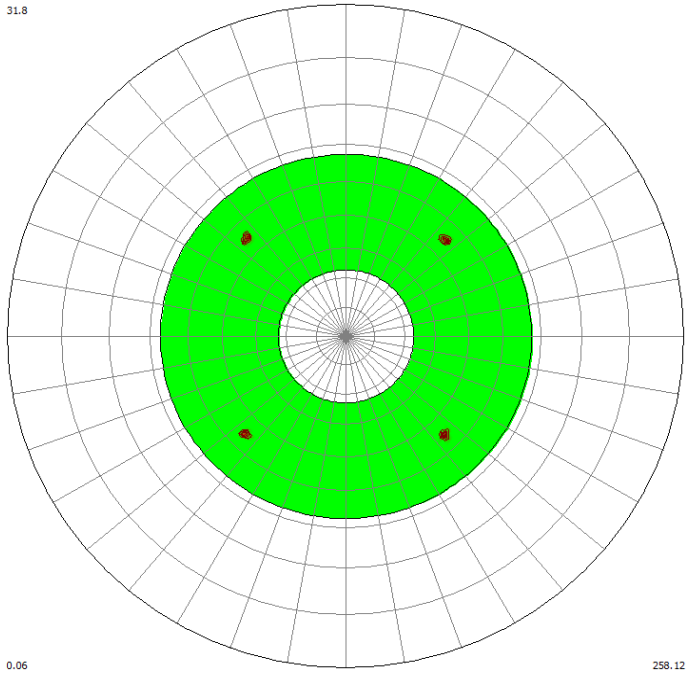
8-inch wafer



Epi-PZT : Crystallinity

- By improving the crystallinity, the relative permittivity of Epi-PZT film becomes low

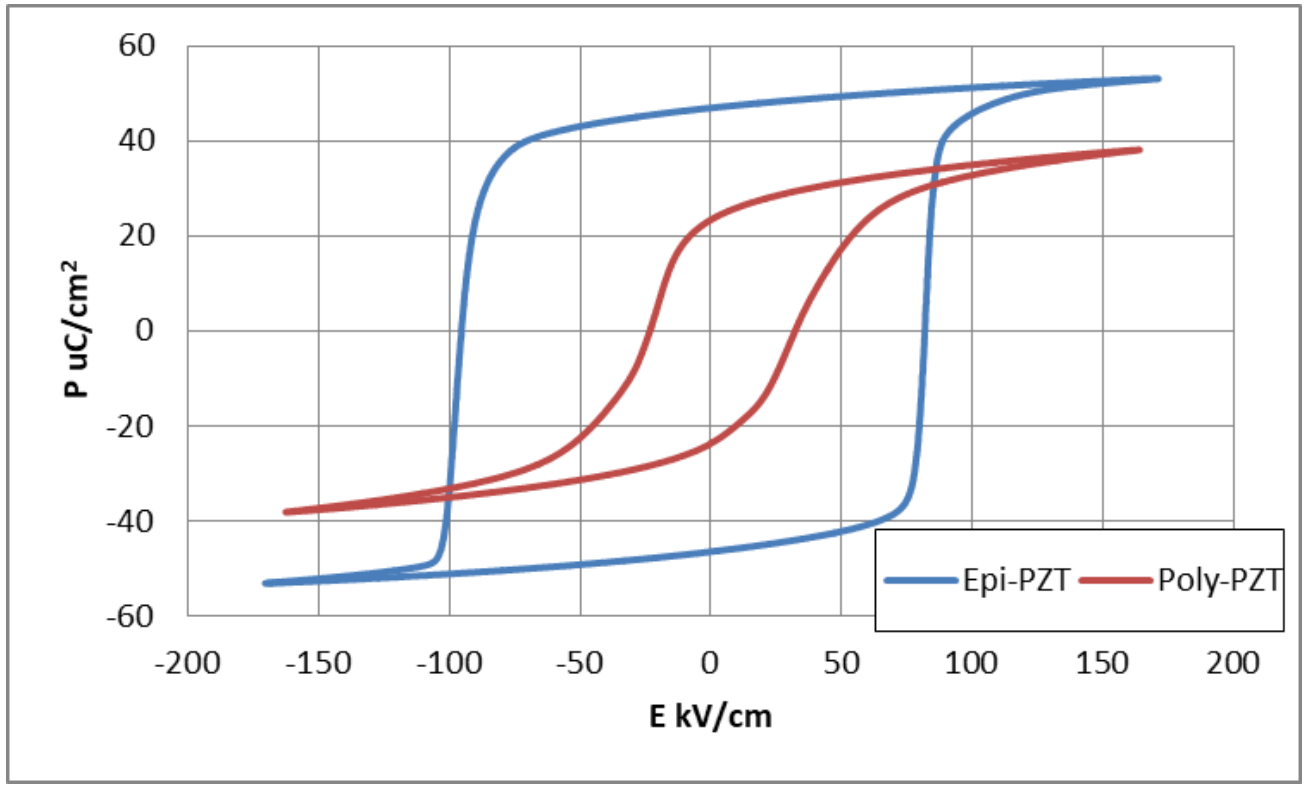
Cross Section of Epi-PZT film



(110) Pole figure

Epi-PZT : P-E Hysteresis

Higher residual polarization and coercive electric field than conventional products



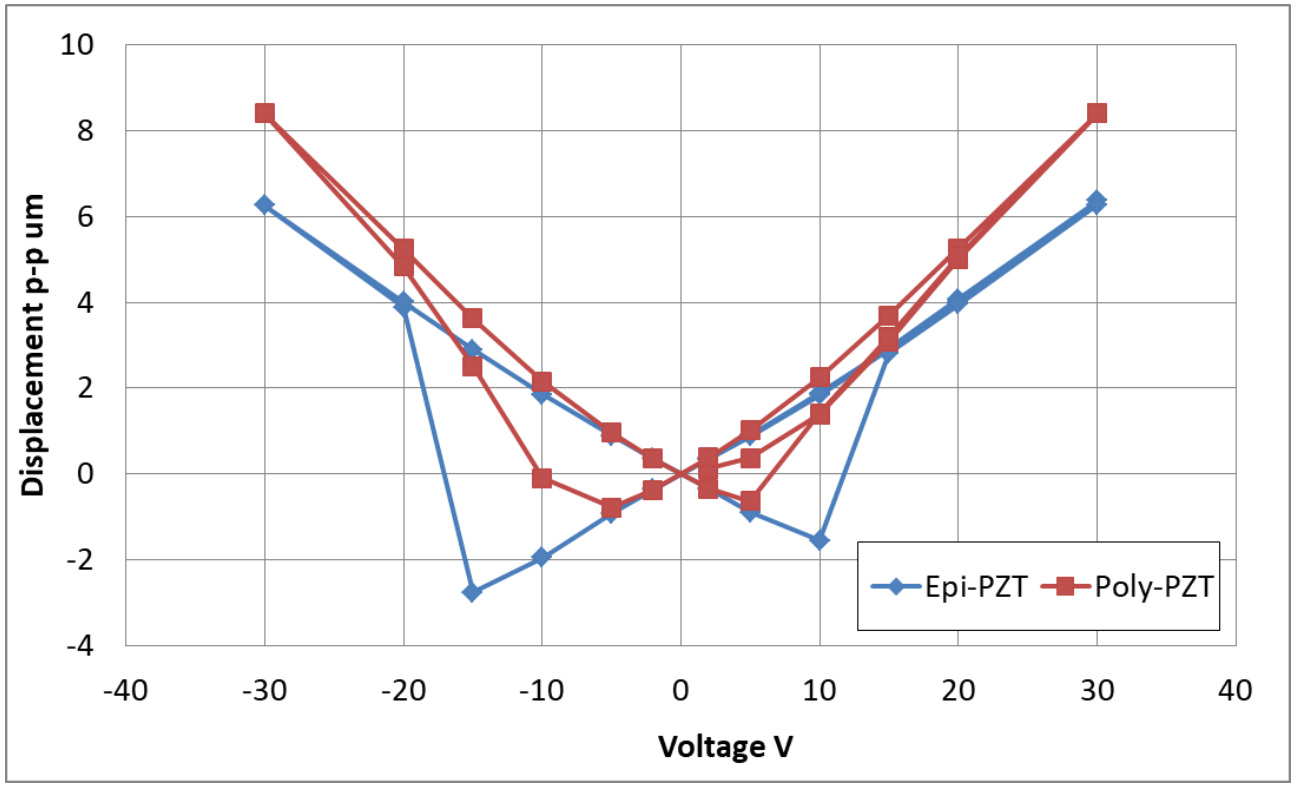
Hysteresis Measurement:

100 Hz, sin wave
top electrode ground

+Pr=46.9μC/cm²
-Pr=46.4μC/cm²
+Ec=81.9kV/cm
-Ec=95.4kV/cm

Epi-PZT : d_{31} Butterfly Curve

Can be used in a wider applied voltage range than Poly-PZT

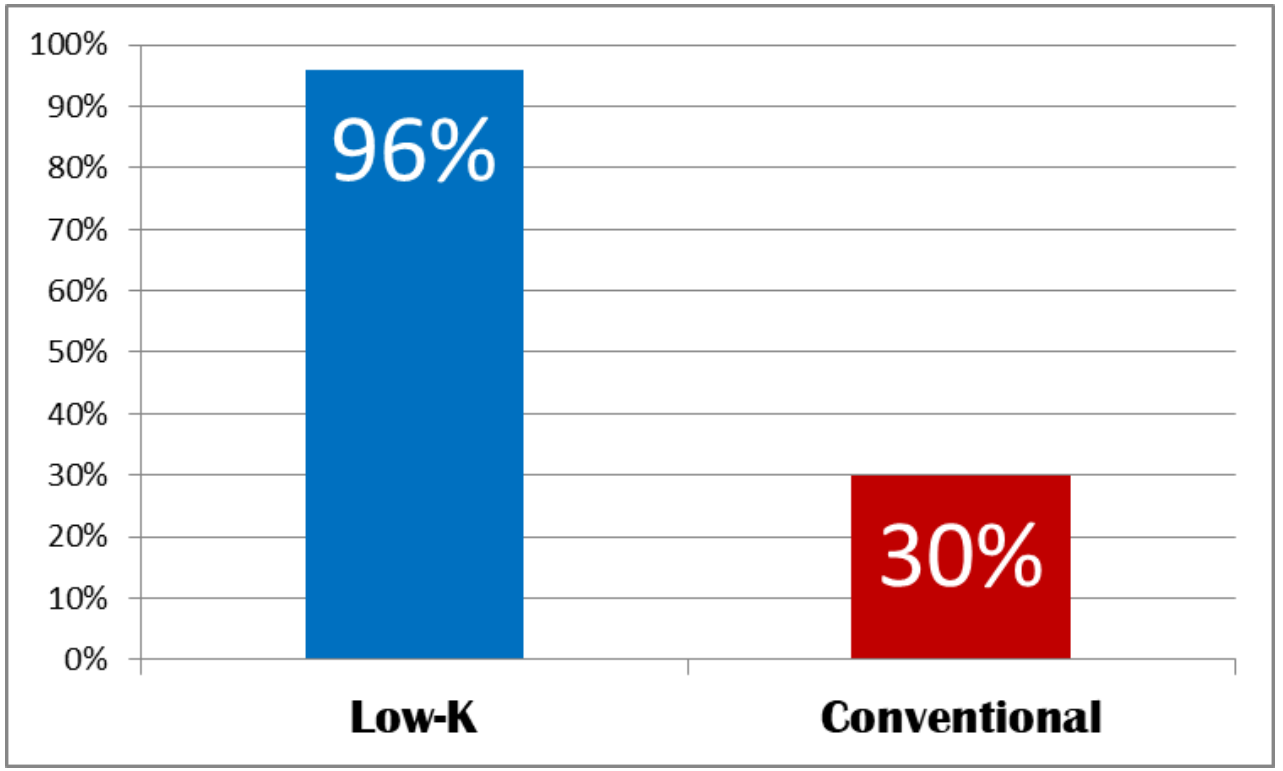


Appropriate for low voltage, bipolar use

Epi-PZT : Spontaneous poling

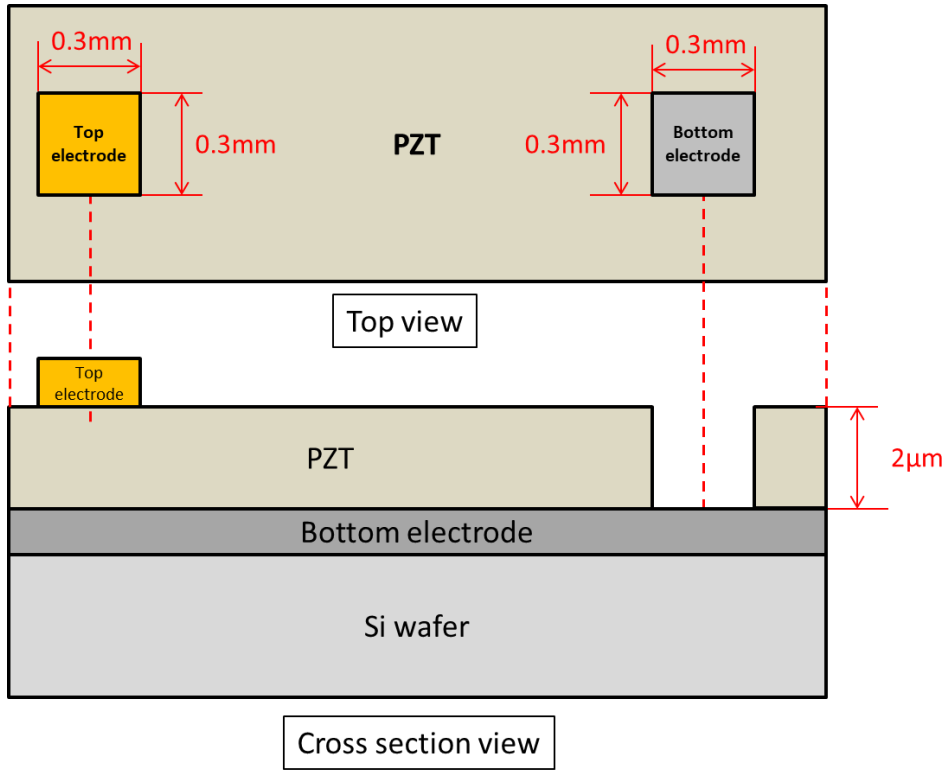
Change of d_{31} of Epi-PZT by poling treatment is small

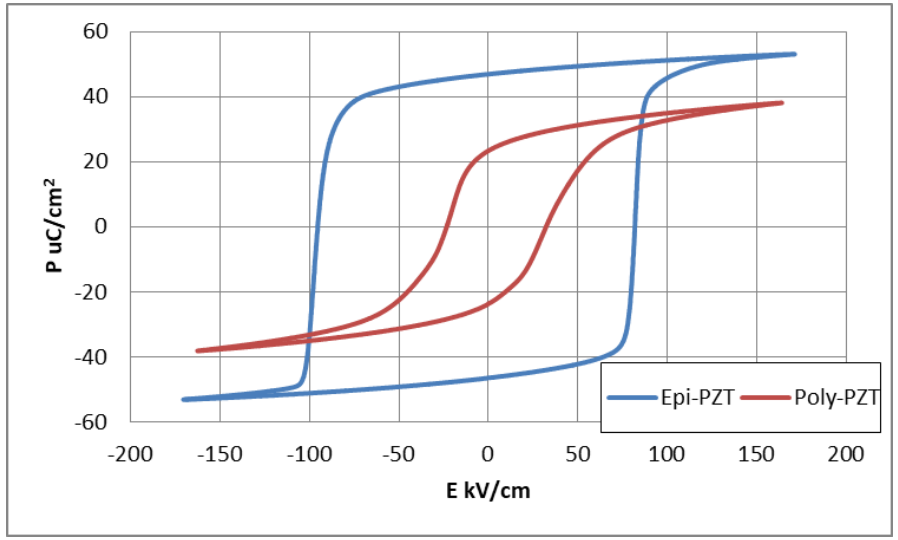
*d_{31} is the value at 2V



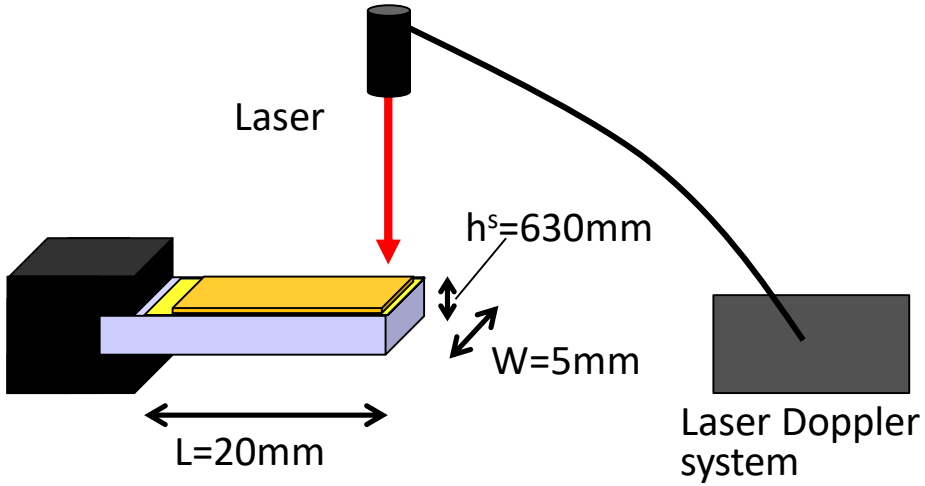
Characterization : P-E Hysteresis Measurement

TEG Pattern Structure

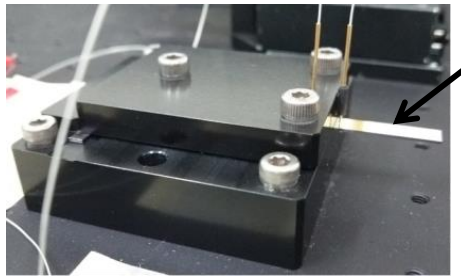




Characterization : d_{31} Measurement



Voltage : 0-30V sin wave / 500Hz
Bottom electrode : +
Top electrode : GND (-)



Measurement tool

Calculating formula of Piezoelectric coefficient d_{31}

$$-d31 \simeq \frac{(h^s)^2 \cdot S^p_{11}}{3 \cdot S^s_{11} \cdot L^2 \cdot V} \delta$$

I. Kanno et al. / Sensors and Actuators A 107 (2003) 68–74

h^s : Thickness of silicon cantilever

S^p_{11} : Elastic compliance of PZT film
→1/(70×10^9Pa) assumed value

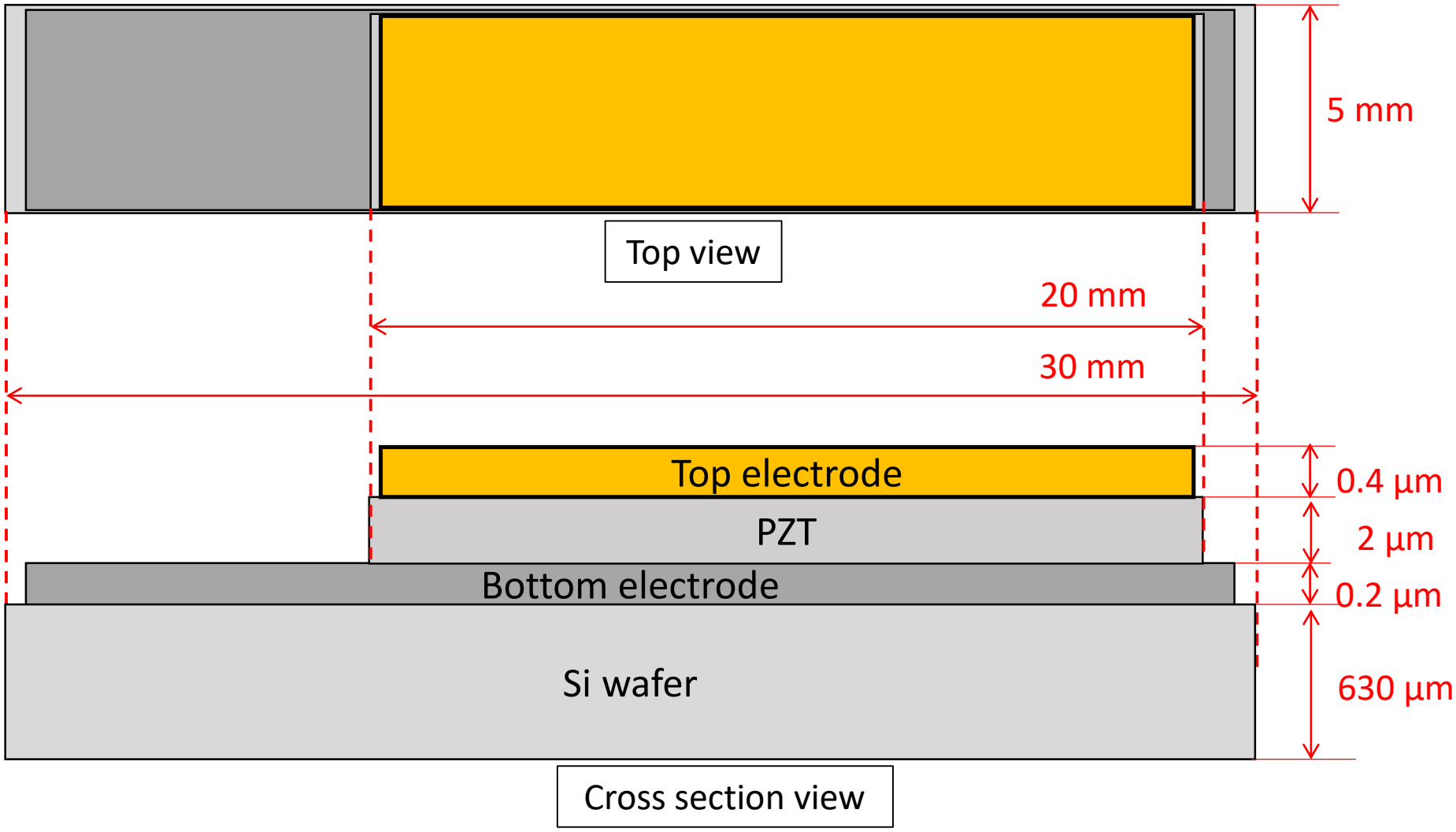
S^s_{11} : Elastic compliance of silicon
→1/(168.9×10^9Pa)

L : Length of silicon cantilever

V : Applied voltage

δ : Displacement of cantilever

Characterization : Cantilever for d_{31} Measurement

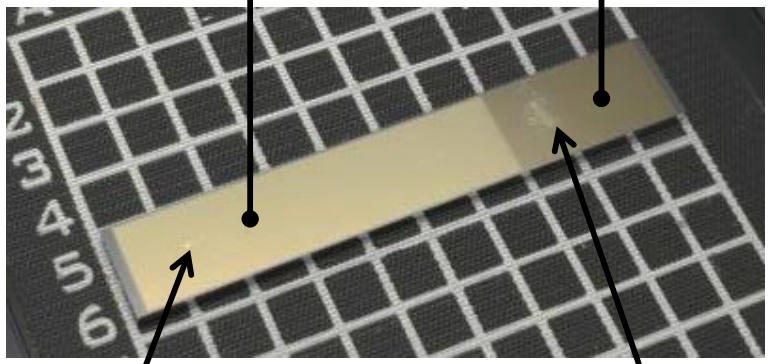


Characterization : Dielectric Constant Measurement

Dielectric constant is derived from measured value of capacitance

LCR meter
ZM2353, NF corporation

Measurement condition: 1kHz/±1V



Top electrode Bottom electrode

Dielectric constant: $e = C \times d/(e_0 \times S)$

e_0: Dielectric constant of vacuum
C: Capacitance of PZT
d: Thickness of PZT
S: Area of top electrode (5 x 20mm^2)

Summary

- ✓ Poly-PZT
  - The world highest level FOM for actuator (=-d_{31}) : 240pm/V
  - Commercially available
- ✓ Epi-PZT
  - 2 kinds of films: Higher d_{31} and Lower ε_r
  - The world highest level FOM for transducer ($\propto(d_{31}{}^2)/\varepsilon_r$) : 52 GPa
  - Other advantages: Low voltage, Bipolar use
  - Samples available
- ✓ Novel-PZT
  - Intermediate feature between Poly-PZT and Epi-PZT
  - Appropriate for low voltage, bipolar actuator use
  - Samples available
- ✓ We can provide these films and subsequent MEMS foundry service.
- ✓ MEMS Business Development Support including device designing is also available.

Thank you