Formation mechanism of PLD-derived $Pb(Mg_{1/3}Nb_{2/3})O_3$ - $PbTiO_3$ thin films

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Student Speech Contest

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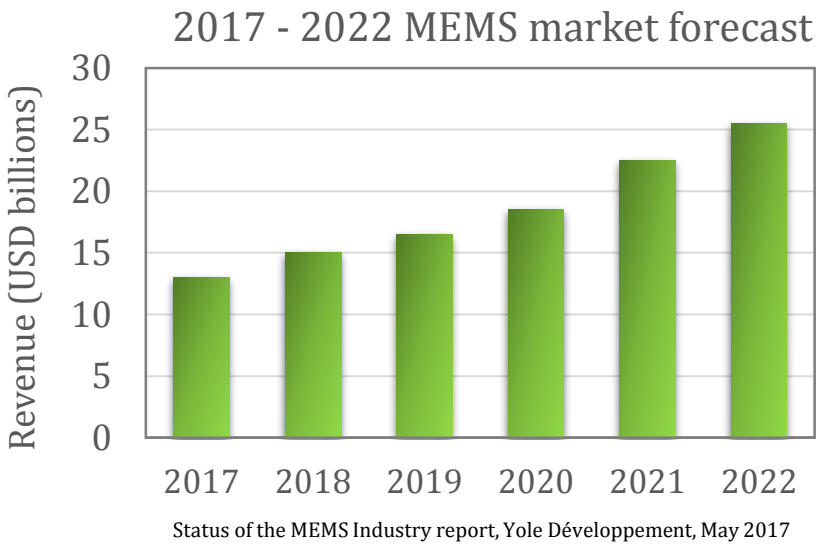
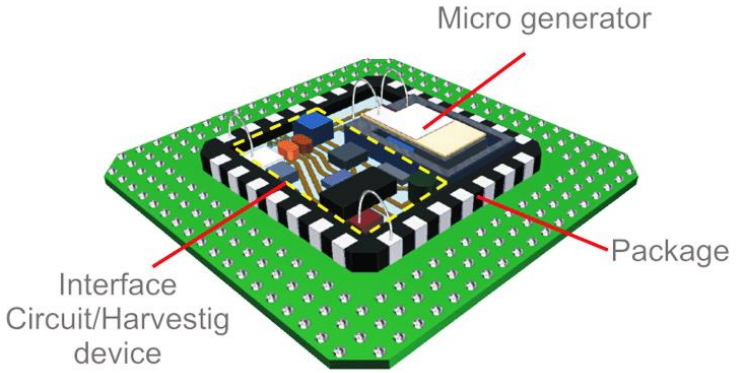
Piezoelectrics

Piezoelectric microelectromechanical systems (piezoMEMS)

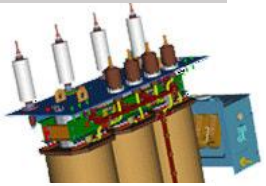


Status of the MEMS Industry report, Yole Développement, May 2017

Vibration energy harvesting

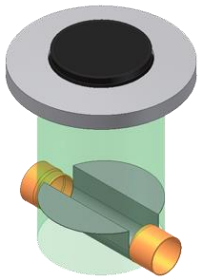


Transformers



Bearings

Water shafts

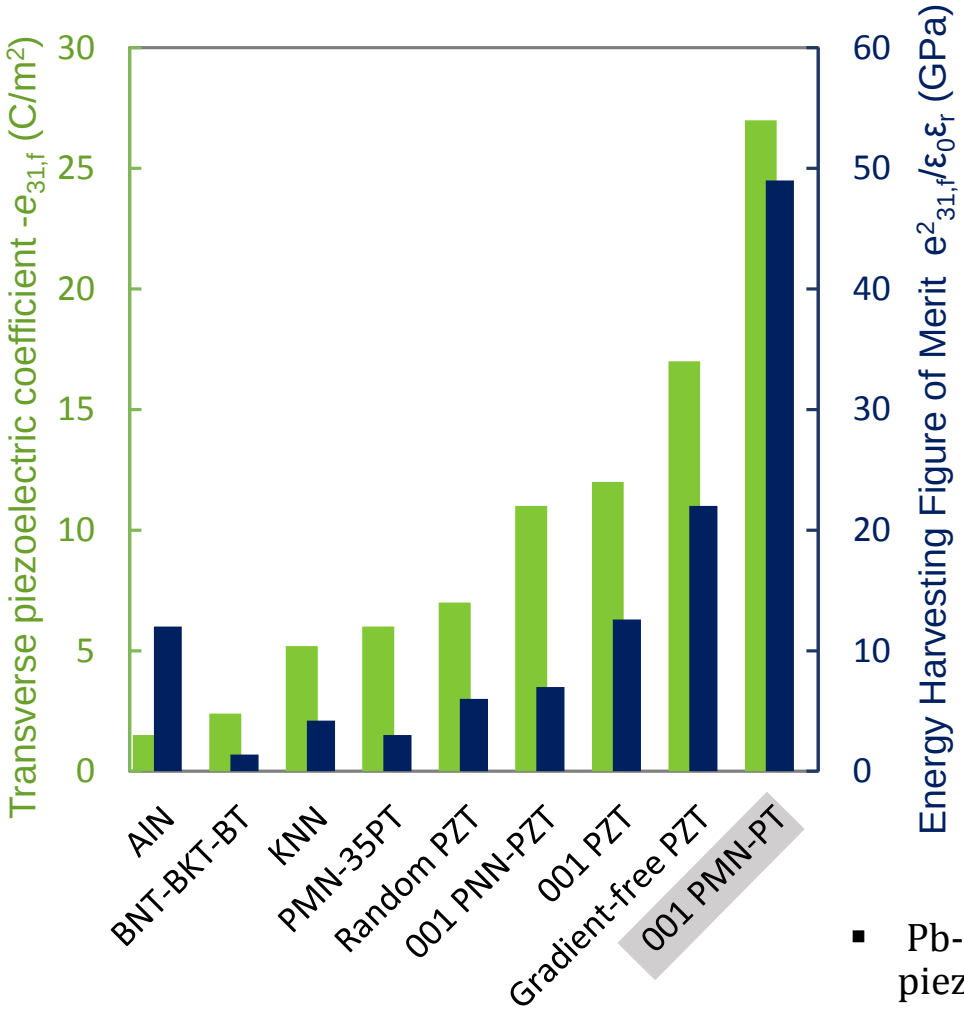


Main device features:

- NO battery (no waste)
- TRUE wireless
- SMALL size
- LONG lifetime
- HIGH temperature resistance

COSYLAB
CONTROL SYSTEM LABORATORY

Why $Pb(Mg_{1/3}Nb_{2/3})O_3$-$PbTiO_3$?



- PMN-PT exhibits excellent piezoelectric properties useful for sensors, actuators, energy harvesters, etc.
- Epitaxial PMN-PT exhibits properties superior to PZT
- Potential for further improvement!

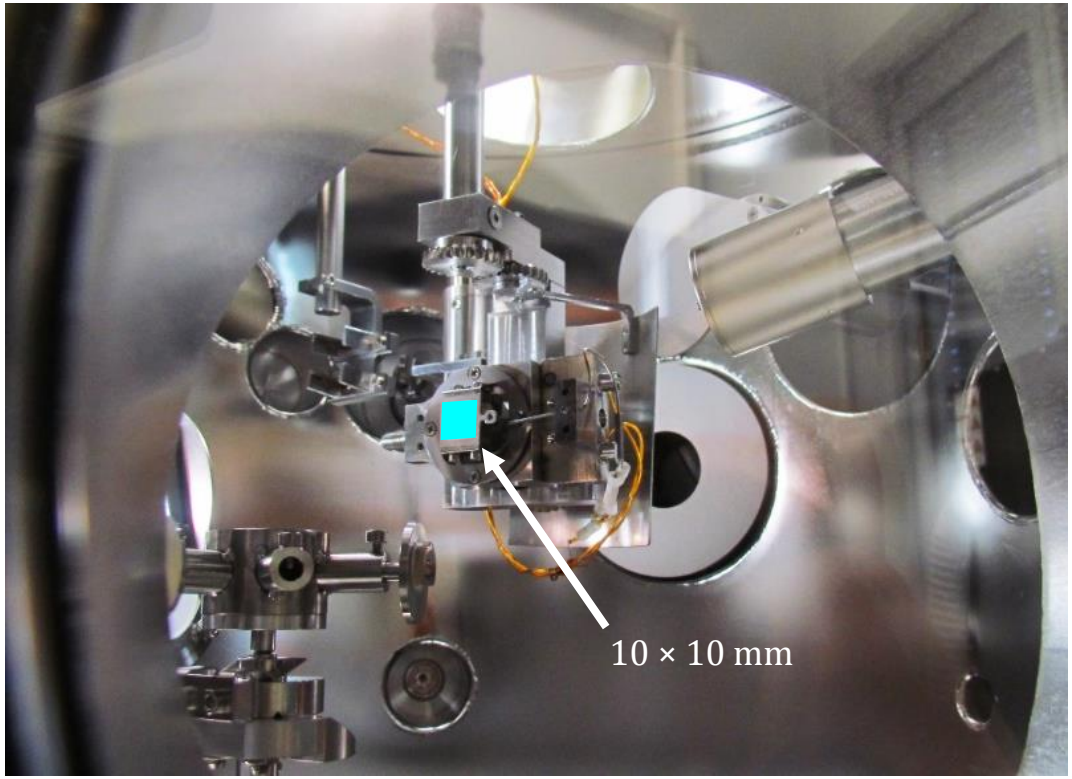
- Pb-based materials still dominate the field of piezoelectrics, except in some niche aplications

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

Why PLD?

Pulsed-laser deposition (PLD)

- Simple and fast
- Flexible/versatile
- Large pressure range
- Precise control of the growth rate
- For many materials the composition of the target is preserved in the transfer to the substrate surface

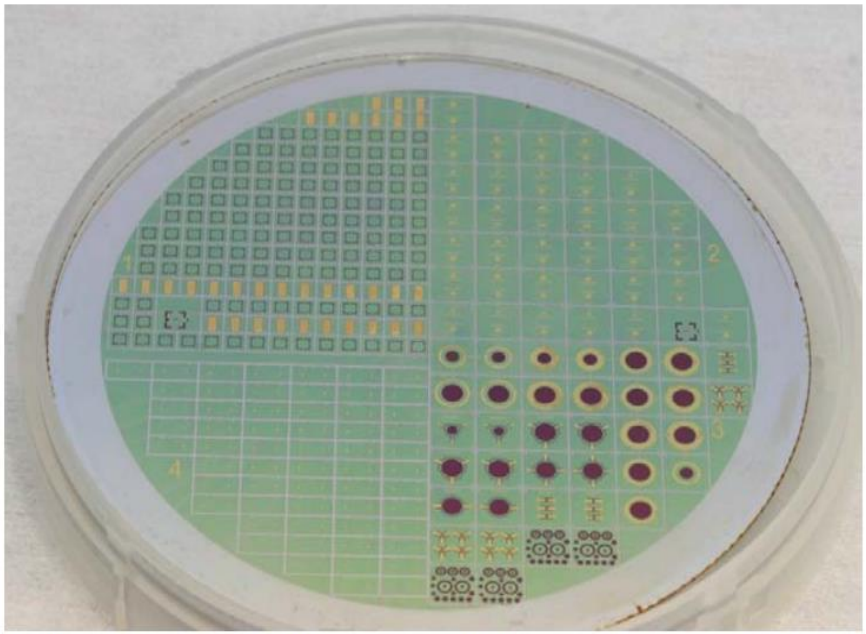


- Scalable – large wafers

SIP 1200 PLD platform for stable thin film manufacturing

SINTEF

Release etch of piezoMEMS wafers

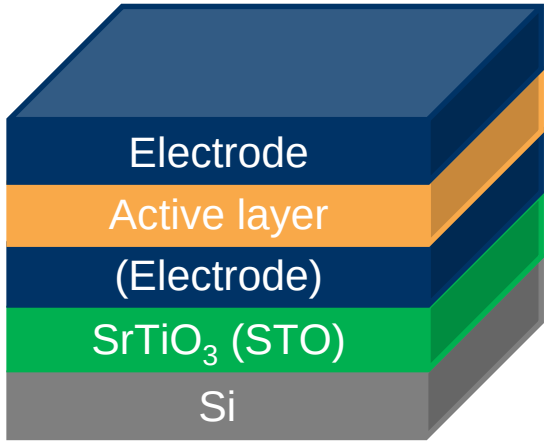


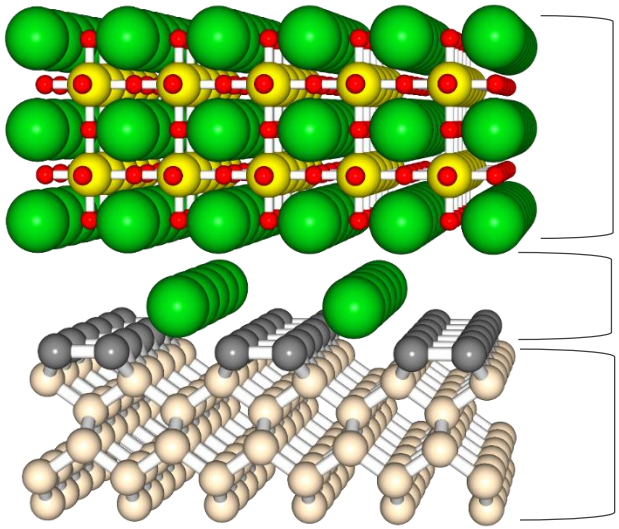
Multi-project piezoMEMS wafer from SINTEF

https://www.sintef.no/globalassets/project/piezovolume/publications/industrial-fabrication-of-piezomems_tyholdt.pdf

But we first need to study the phenomena on a research system

Integration with silicon





$SrTiO_3$

Buffer layer (1/2 monolayer Sr/Si(001) surface)

Si

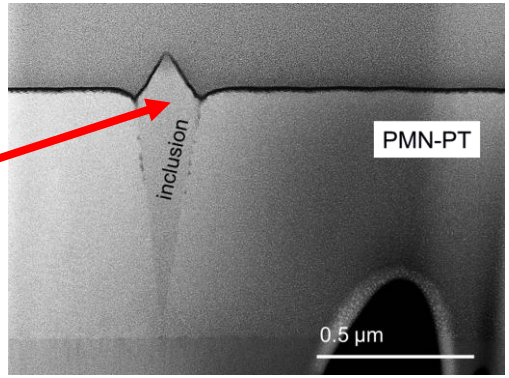
Challenges:

Pulsed-laser deposition (PLD)

- Simple and fast
- Flexible/versatile
- Large pressure range
- Precise control of the growth rate
- For many materials the composition of the target is preserved in the transfer to the substrate surface

Challenges:

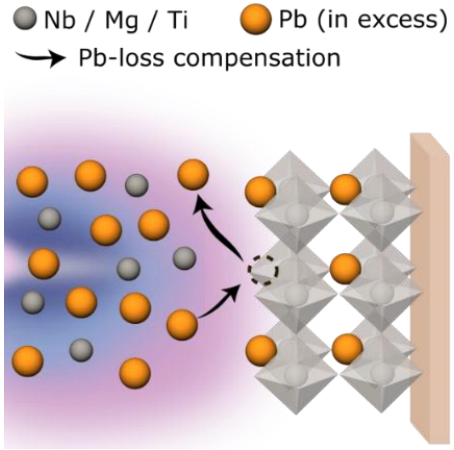
- Multicomponent material



- Volatility of Pb → lead-deficient pyrochlore

- Meticulous control of the growth conditions does not always suffice!

- Pb-loss compensation through the use of Pb-rich targets



How much lead excess?

Targets with different amounts of Pb excess and PMN:PT ratio

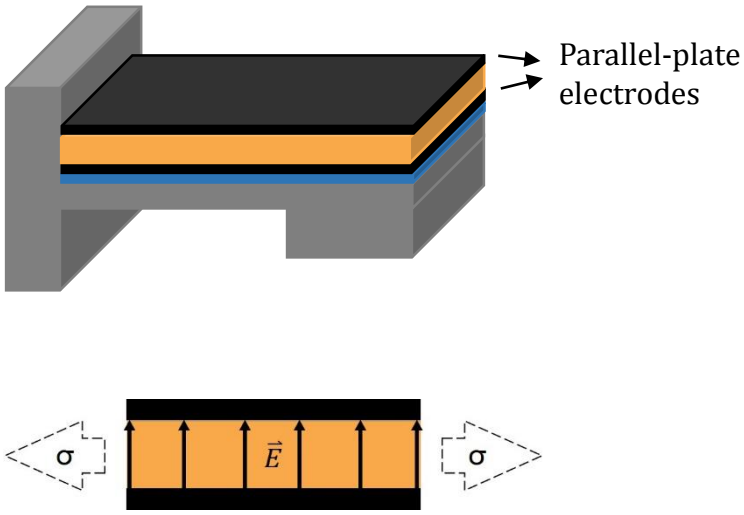
10 mol. %	PMN-25PT
15 mol. %	PMN-33PT
20 mol. %	**PMN-40PT**

Non-stoichiometric transfer and shifted morphotropic phase boundary (MPB)

Design of experiments

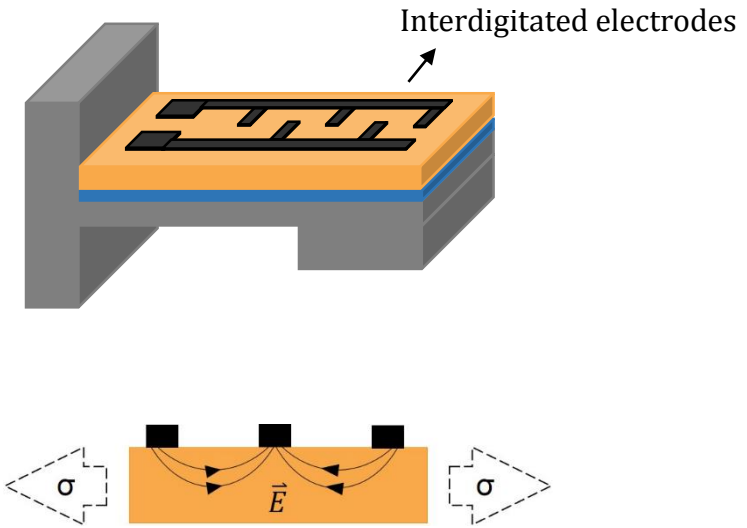
Electrodes
Piezoelectric
$SrTiO_3$ buffer layer
Si or SS cantilever

Transverse (d_{31}) mode



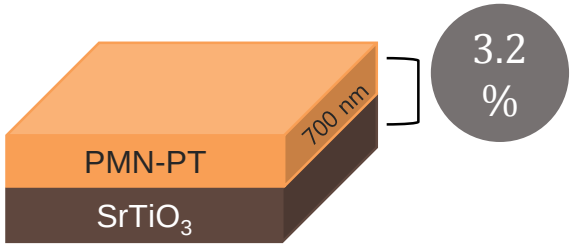
- Most commonly used

Longitudinal (d_{33}) mode



- Higher electromechanical coupling
- Higher achievable voltages due to the higher piezoelectric constant and adjustable electrode spacings

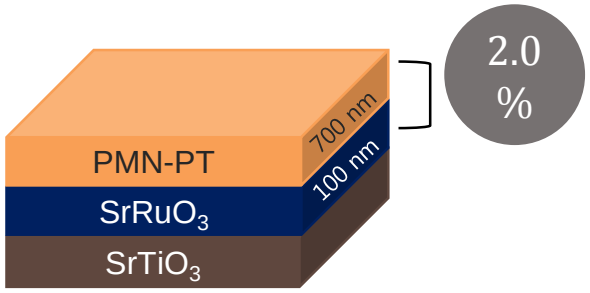
PMN-40PT / STO



PbO excess required:

YES

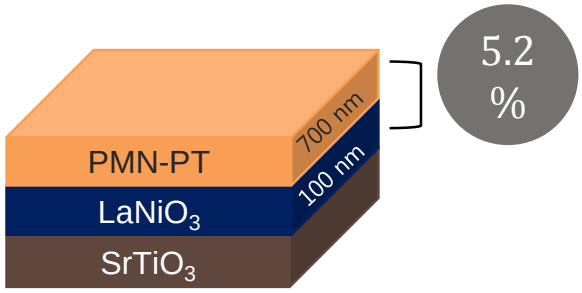
20 mol. %



PbO excess required:

YES

10 mol. %

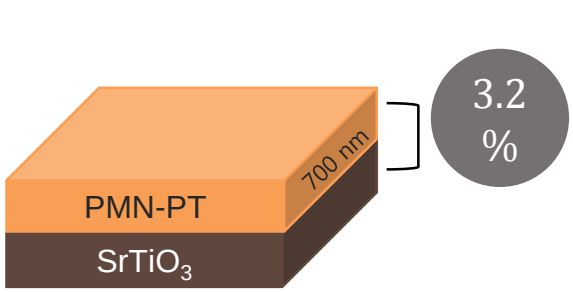


PbO excess required:

NO

LNO strongly stabilizes the perovskite phase

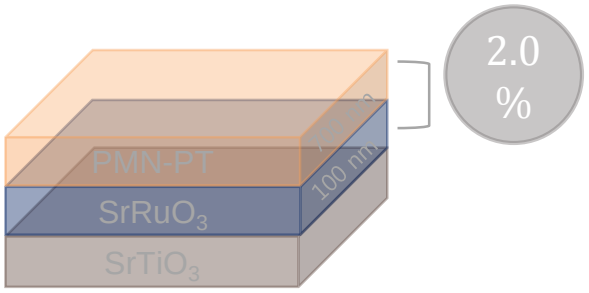
PMN-40PT / STO



PbO excess required:

YES

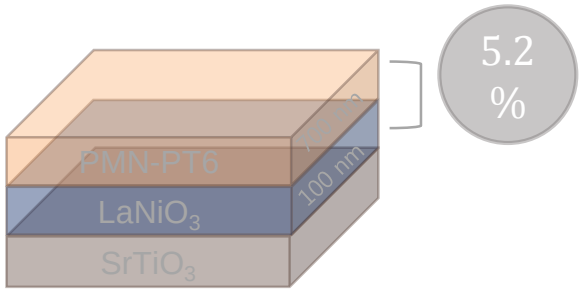
20 mol. %



PbO excess required::

YES

10 mol. %

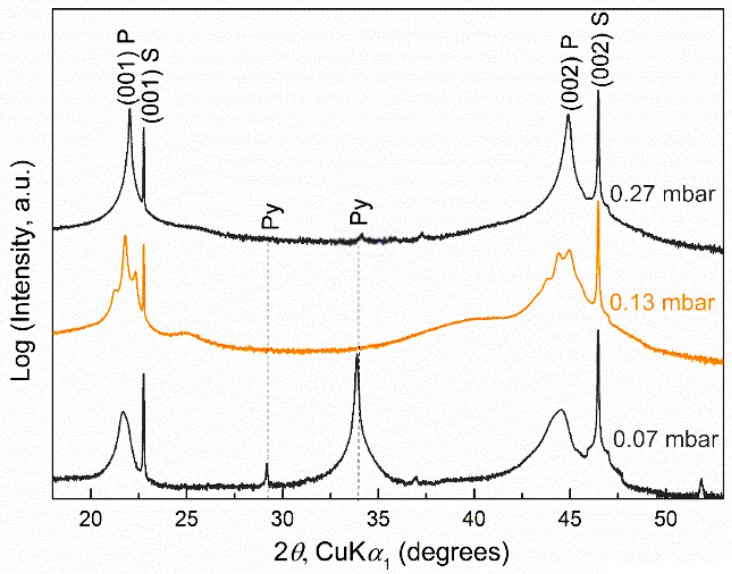


PbO excess required:

NO

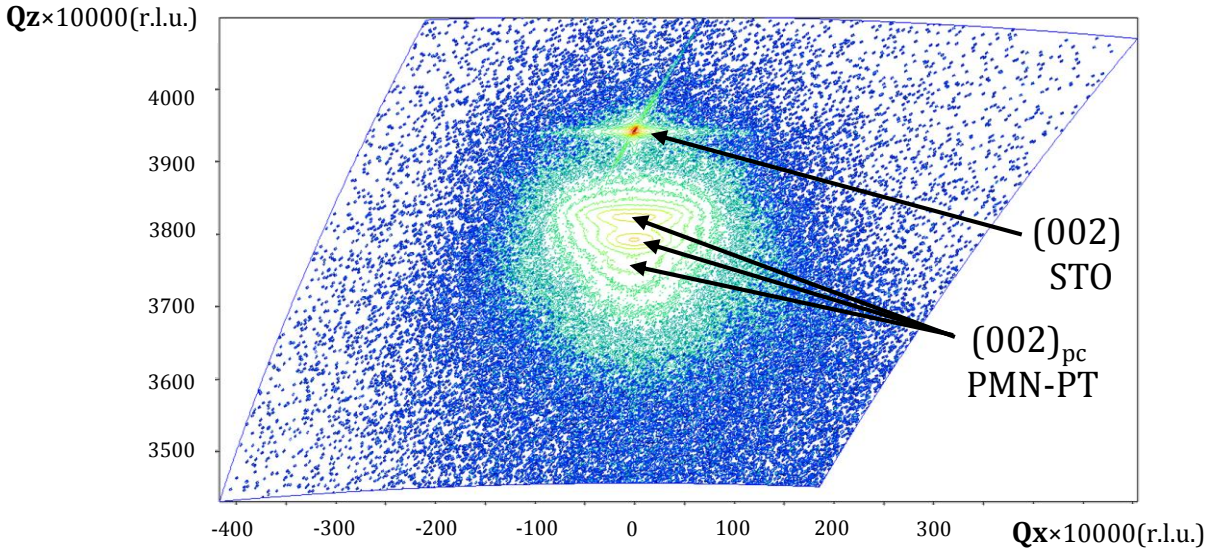
LNO strongly stabilizes the perovskite phase

PMN-40PT + 20 mol. % PbO / STO



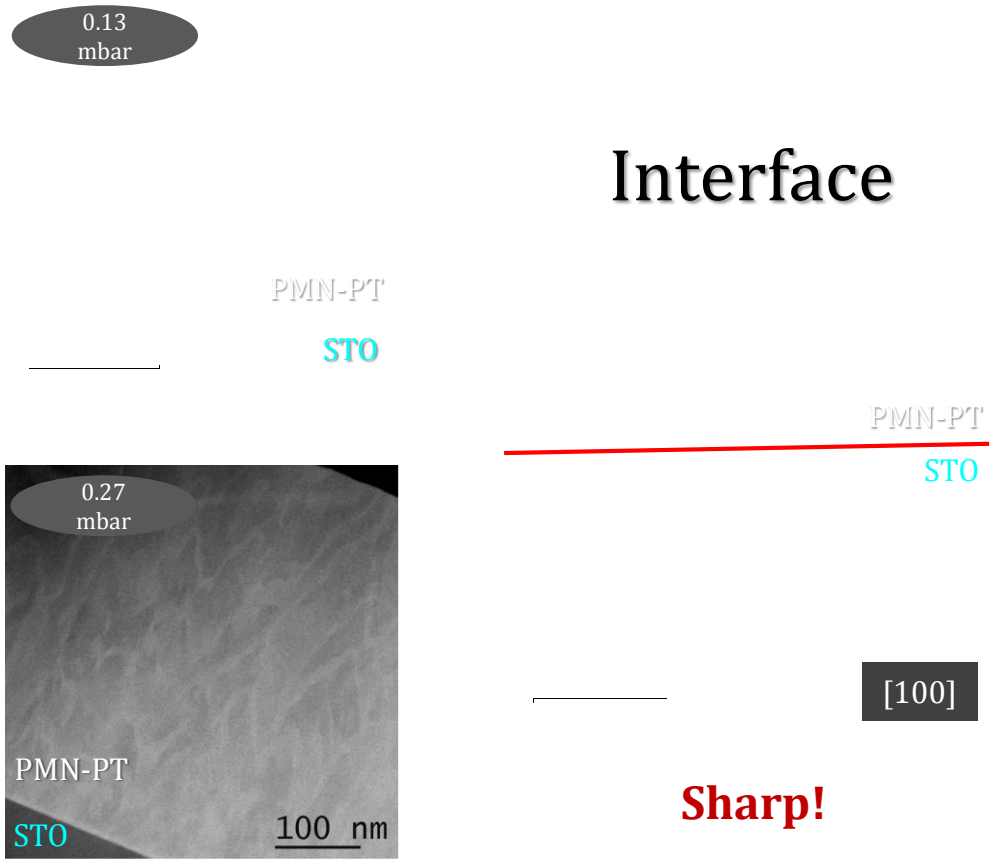
- Process pressure strongly influences phase purity
- Broad $(00l)_{pc}$ peak splitting indicates strong inhomogeneity – not MPB
- Peak splitting absent in films prepared from targets without Pb-excess, but also observed in bulk ceramic samples

Oxygen deficiency is not the reason for the splitting – shown by experiments with O_2/Ar mixture



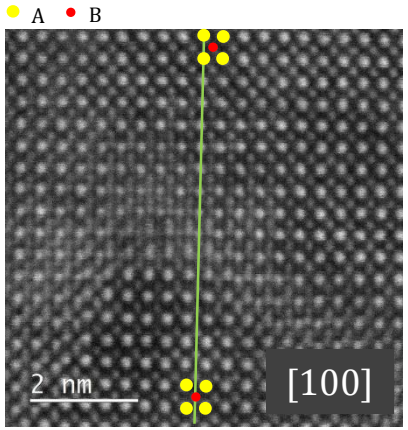
TEM cross-sections

PMN-40PT + 20 mol. % PbO / STO



Interface

Antiphase boundaries



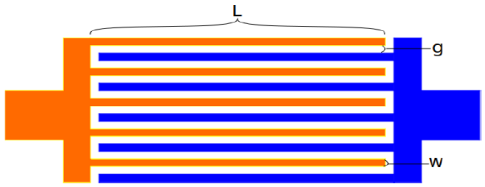
Sharp!

- In both samples
- Defects form close to the interface…

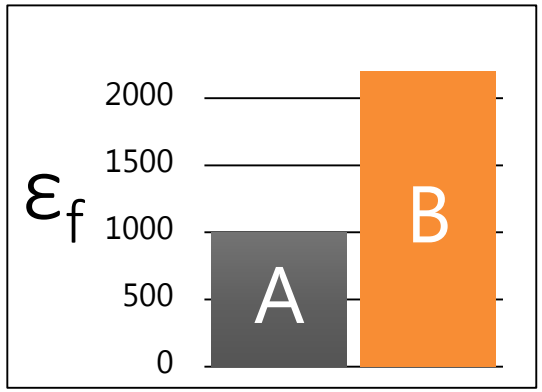
… and propagate throughout the films

Longitudinal design

- Nb-doped STO
- Interdigital electrodes (IDE)



L digit length
w digit width
g interdigital spacing

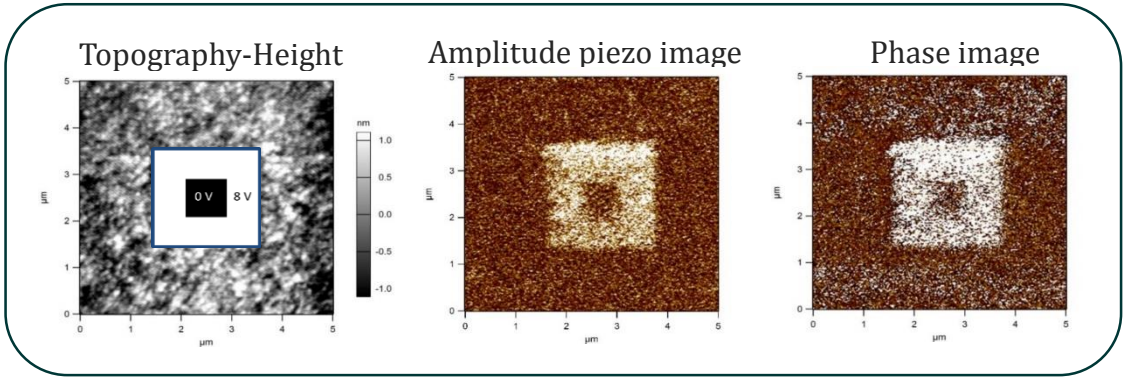


ε_f permittivity of the film

A film prepared at 0.13 mbar
B film prepared at 0.27 mbar

Piezoelectric coefficients low – films are clamped!

PFM litography (in-situ poling)



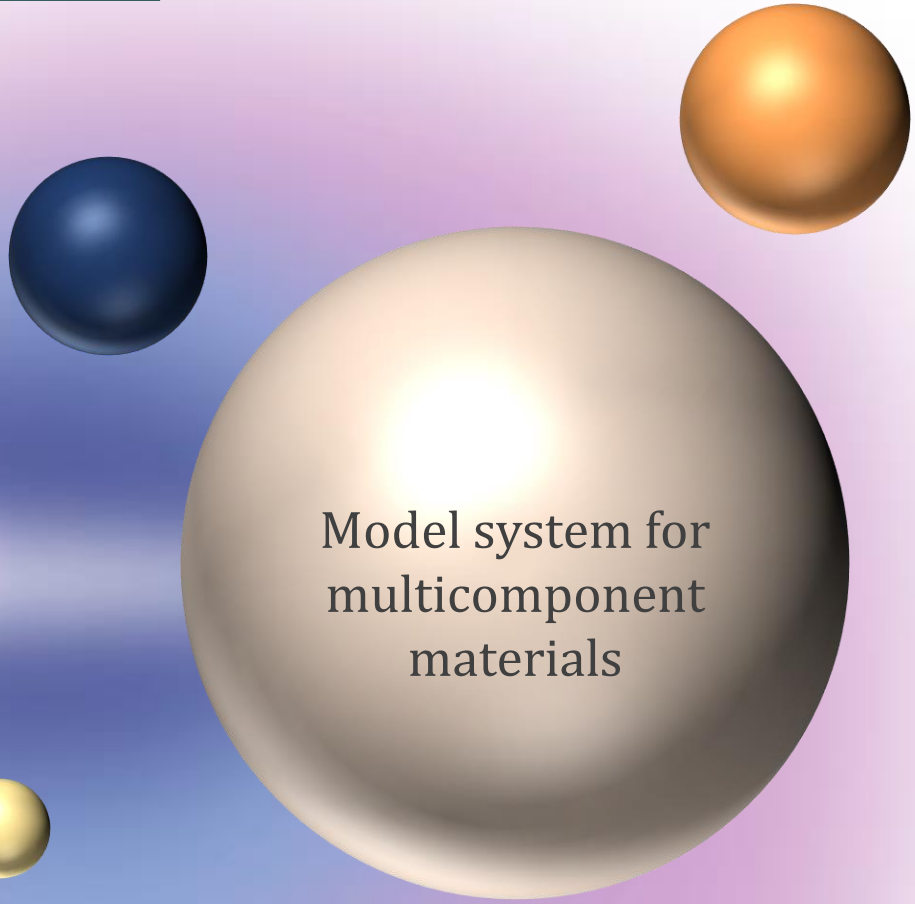
Good domain mobility

Transverse design

Parallel plate capacitor structure with Au top electrodes

- LNO electrodes

Conclusions



Plasma-plume dynamics (pressure)
extremely important!

Thank you!

Prof. Danilo Suvorov **Dr. Matjaž Spreitzer**

- Damjan Vengust, Advanced Materials Department, Jožef Stefan Institute
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- Tjaša Parkelj, Advanced Materials Department, Jožef Stefan Institute
- Dr. Hana Uršič, Electronic Ceramics, Jožef Stefan Institute
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