Influence of Pressure and Temperature on the Growth and Properties of Pulsed Laser Deposited PZT for MEMS

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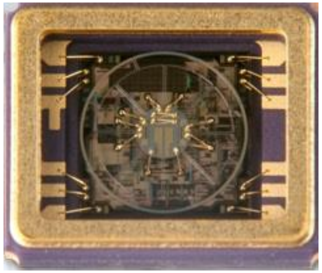
Motivation
PZT for MEMS



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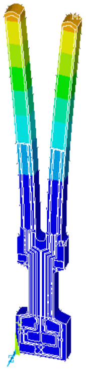

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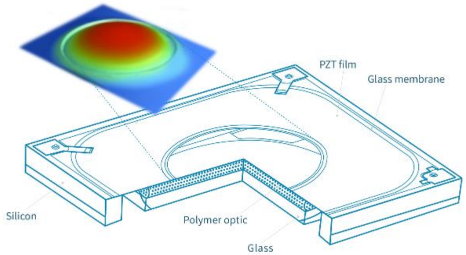
PZT MEMS on the market

- Silicon Sensing: gyroscope with vibrating ring layout
- Panasonic: gyroscope with tuning fork layout
- poLight: autofocus lens
- Foundries: Rohm, SINTEF, Silex Microsystems AB, X-FAB Semiconductor Foundries AG, ...



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Technologically interesting material for MEMS actuators

- High $e_{31,f}$ is needed
- $e_{31,f}$ is dependent on the microstructure*

PZT growth-control is of main interest:

Variation of deposition pressure and temperature influence growth and properties.

* S. Trolier-McKinstry and P. Muralt, J. Electroceram., 12 (2004), pp. 7-17

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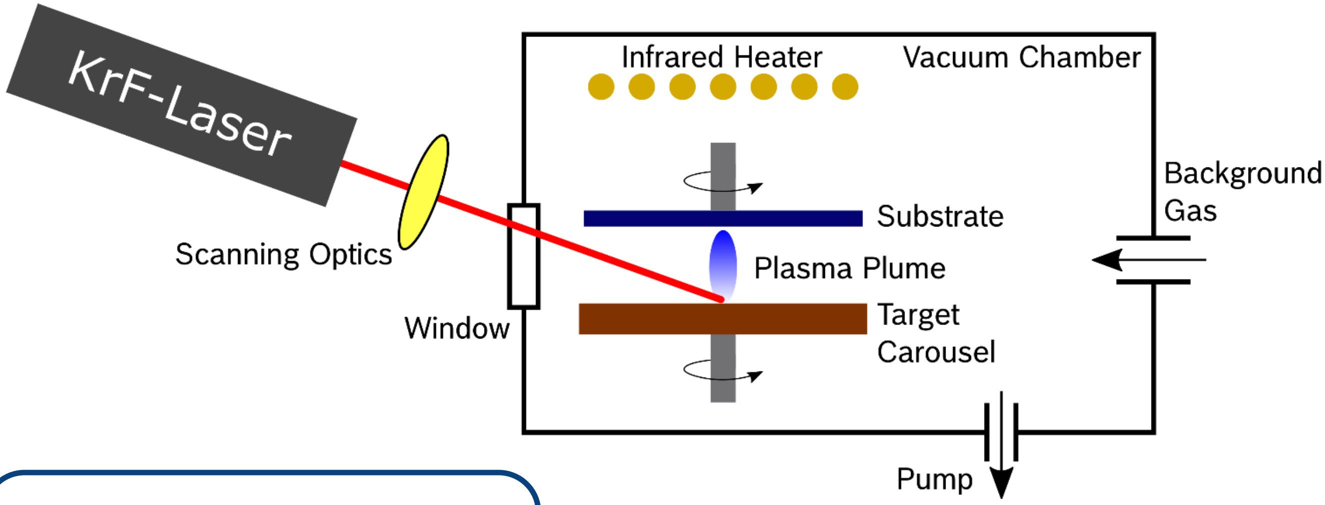
Introduction
Pulsed Laser Deposition

Solmates
PiezoFlare 800

IR heater: up to 800 °C
(445 ≤ T_{dep} ≤ 570 °C used for PZT)

Background gas (here: p_{O2})
range used: 0.05 to 0.20 mbar



Diverse materials: e.g.
PZT, LNO*, SnO_2, CuO, ...

Manifold applications: perfect tool for corporate research

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* LNO = $LaNiO_3$

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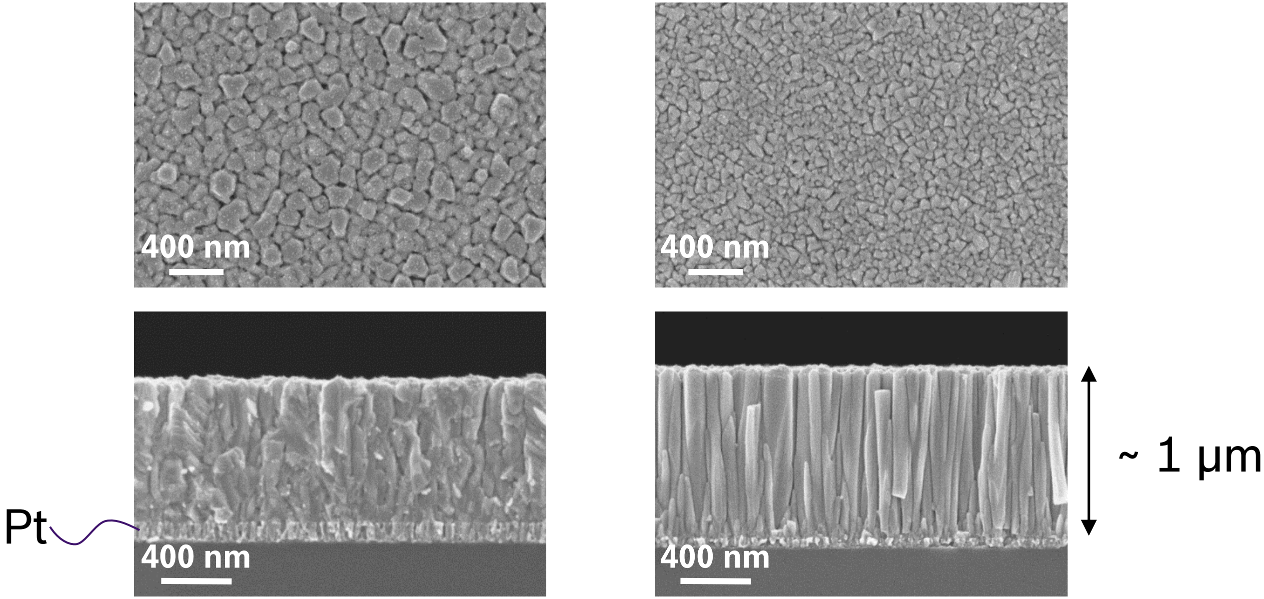
Variation of Pressure (p_{O2})
Microstructure (SEM)

T_{dep} = 570 °C



p_{O2} = 0.05 mbar p_{O2} = 0.20 mbar

$\overline{\varnothing} = 127$ nm

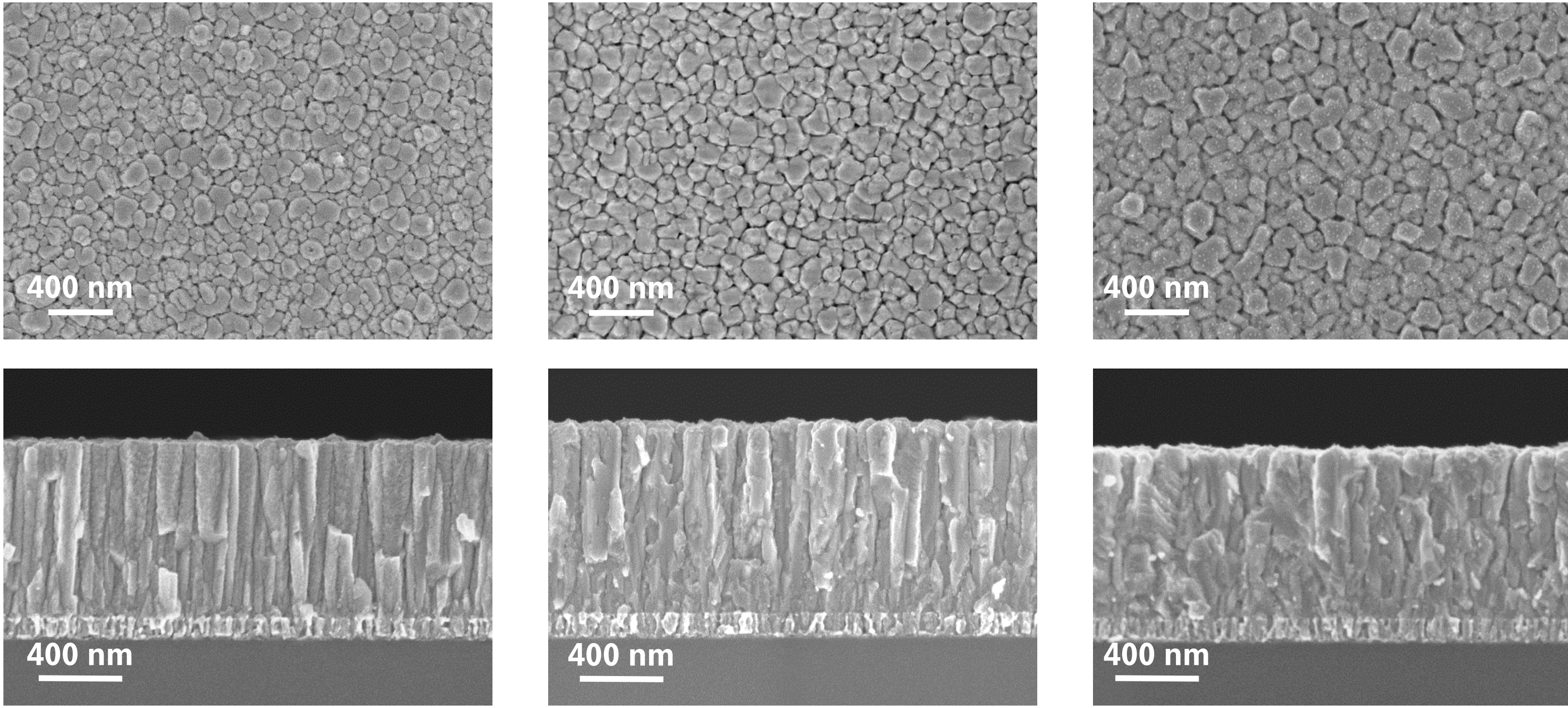
grain size

$\overline{\varnothing} = 64$ nm

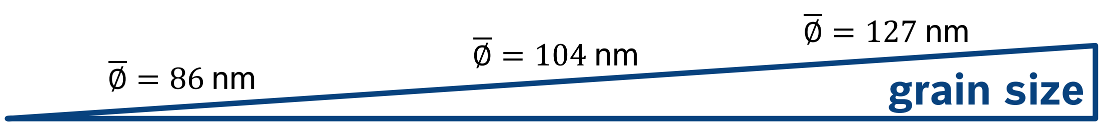
The grain sizes and grain boundaries are effected by the deposition pressure.

Variation of Temperature (T_{dep})
Microstructure (SEM)

p_{O2} = 0.05 mbar



T_{dep} = 445 °C | T_{dep} = 510 °C | T_{dep} = 570 °C



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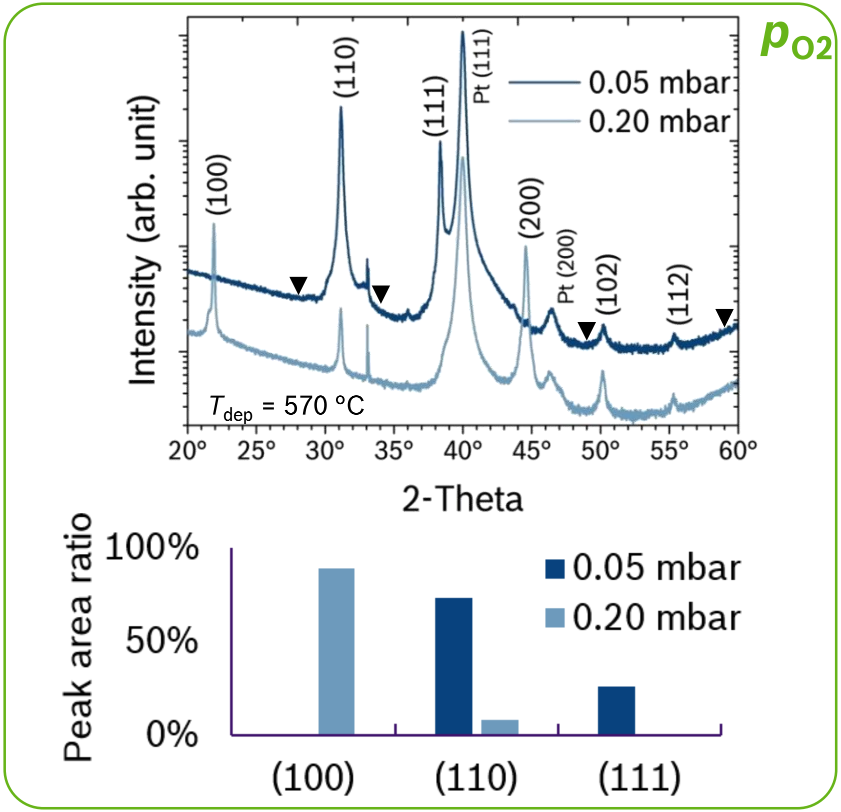
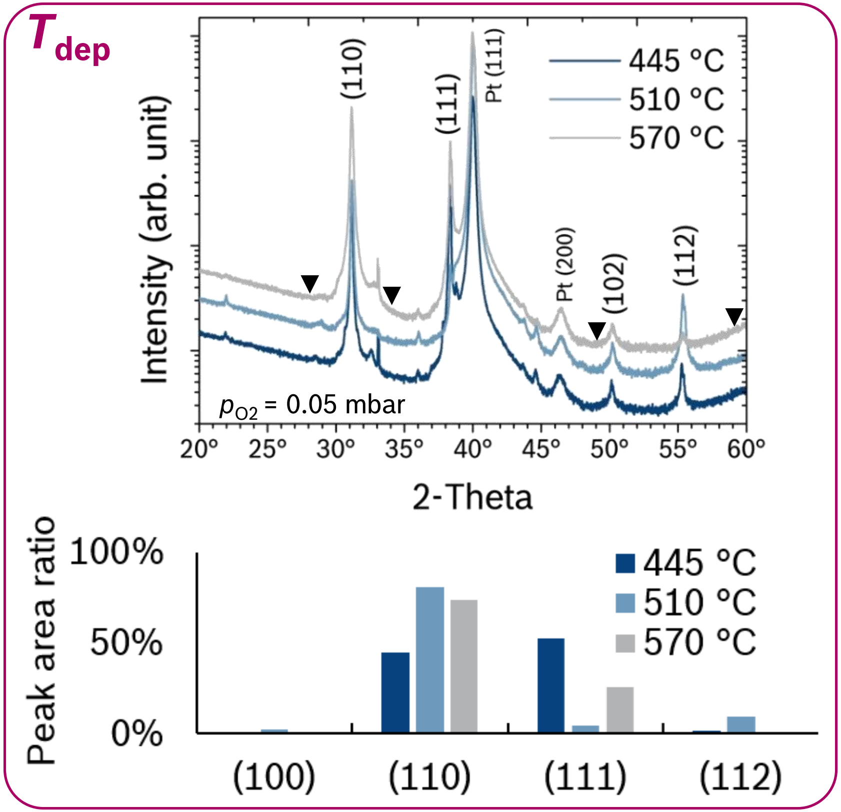
Variation of Pressure / Temperature
Crystalline Phase (XRD)

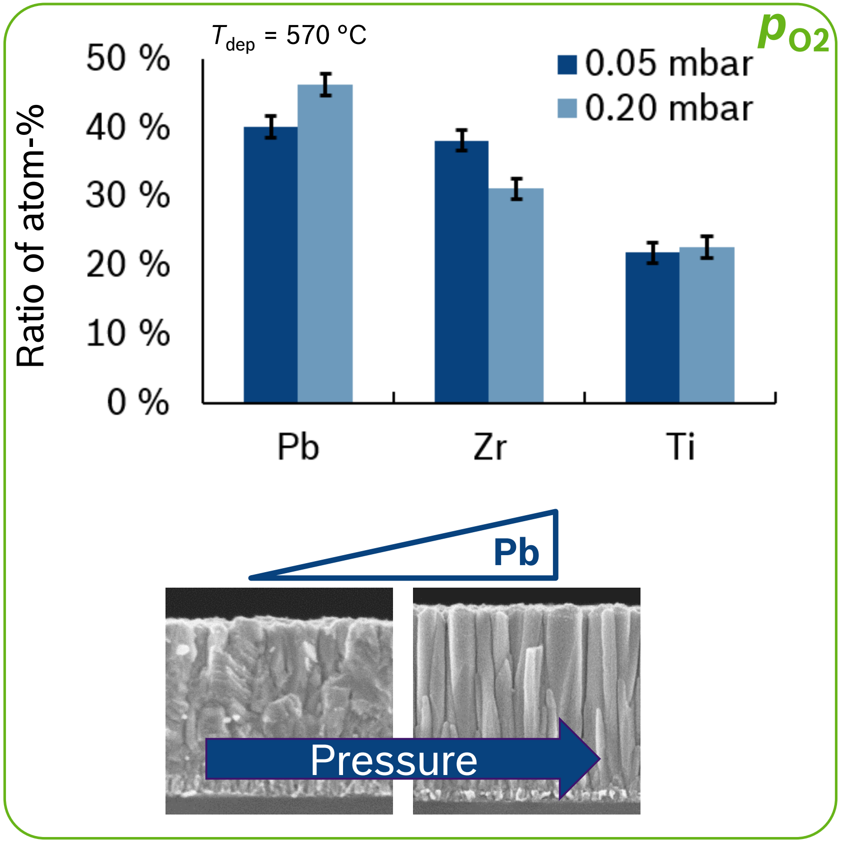


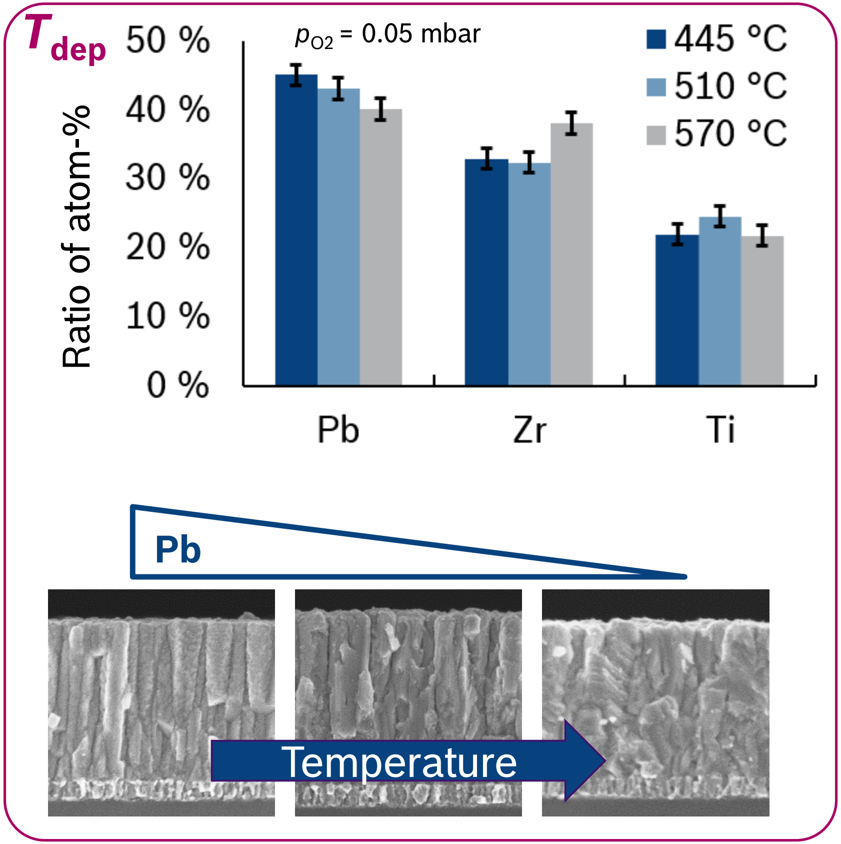


Pressure and temperature have significant influence on the crystalline phase but no clear trend is visible.

▼ pyrochlore peak positions (no peaks visible)

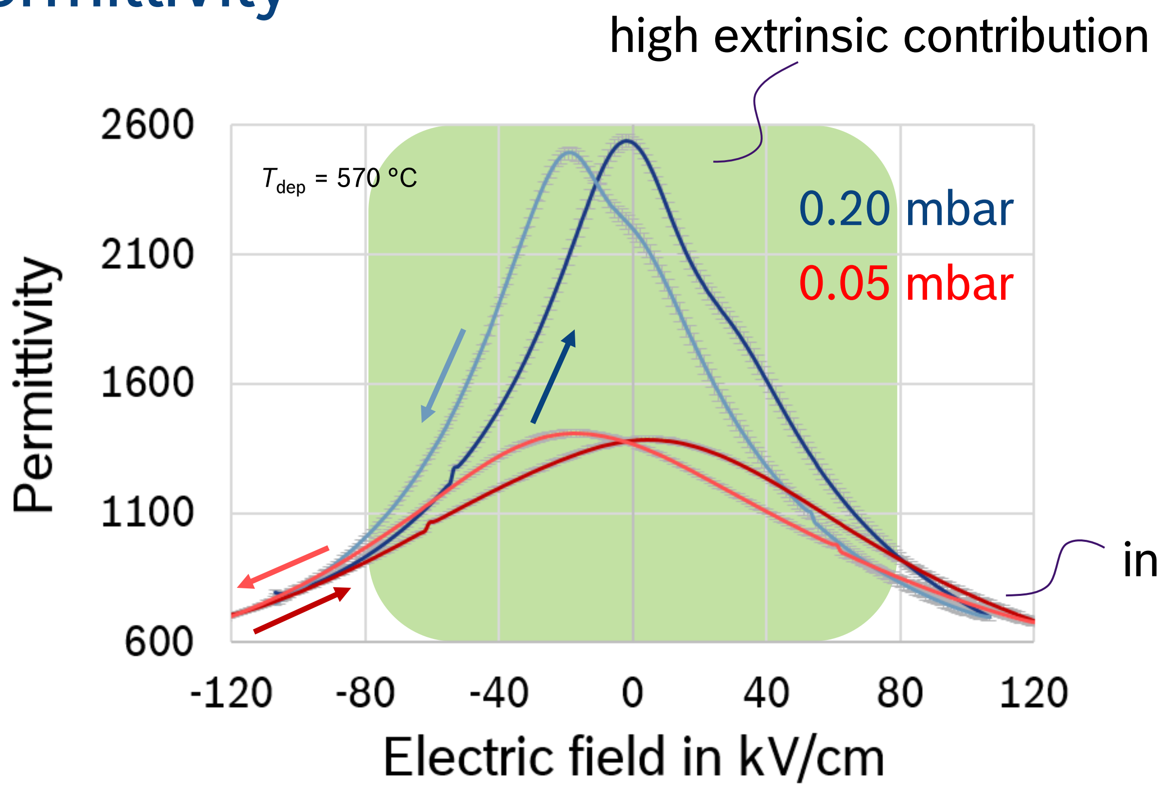
Variation of Pressure / Temperature
Atomic Composition (EDX)

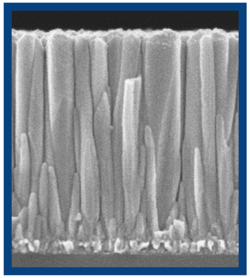


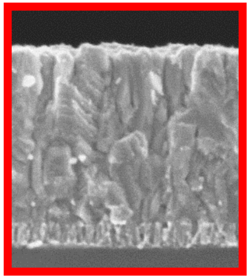


The lead content of the film correlates with the microstructure.

Variation of Pressure (p_{O2})
Permittivity

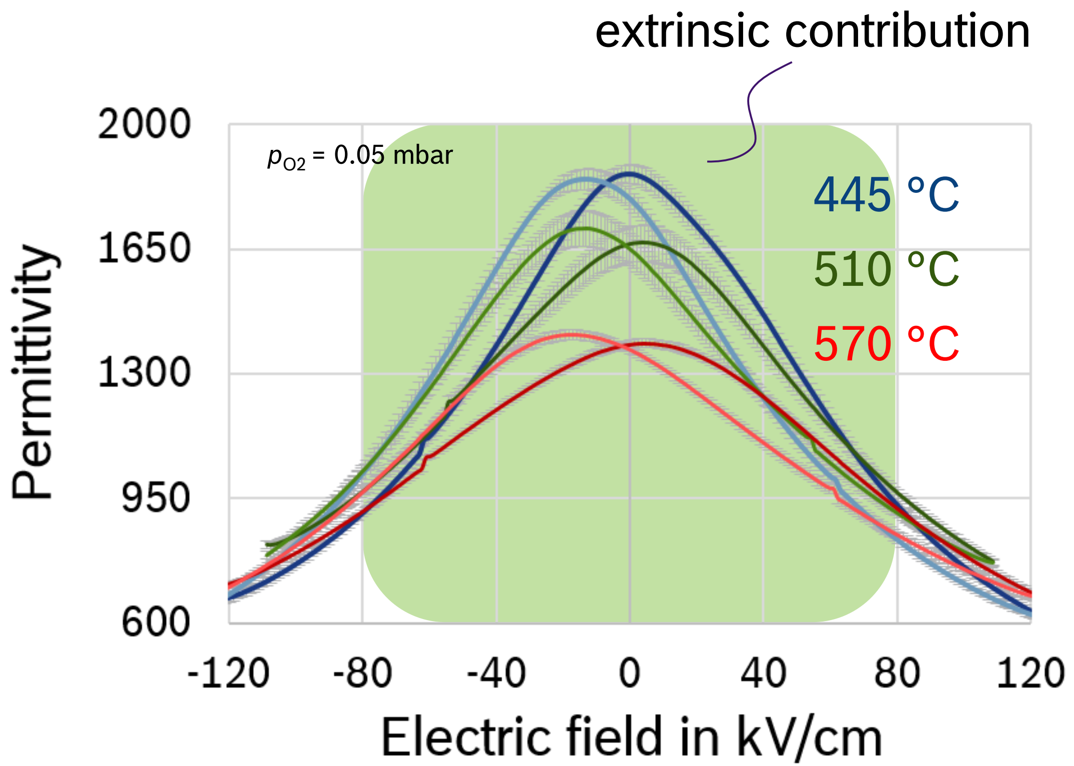


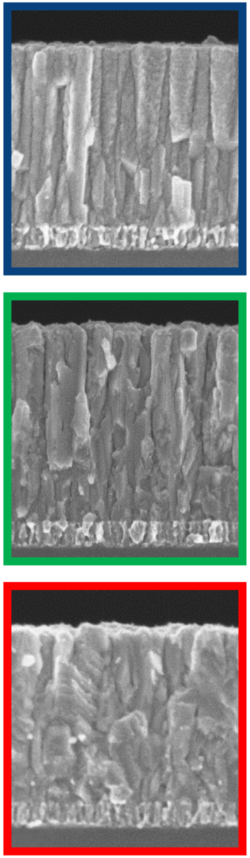




The domain mobility of the film deposited at 0.20 mbar seems to be much higher.

Variation of Temperature (T_{dep})
Permittivity





The mobility of the domains decreases with increasing deposition temperatures.

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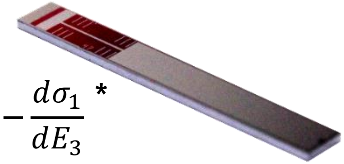
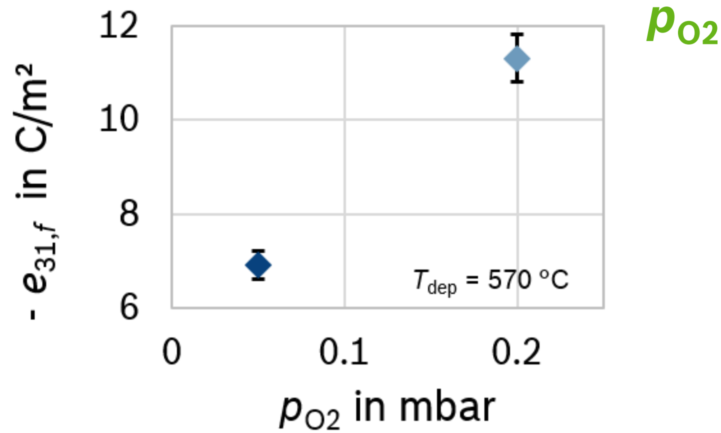
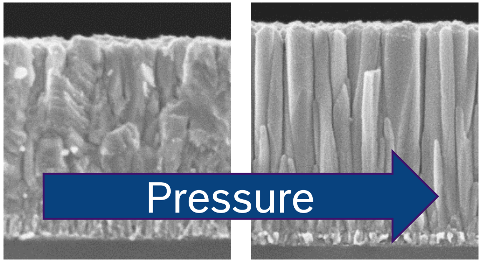
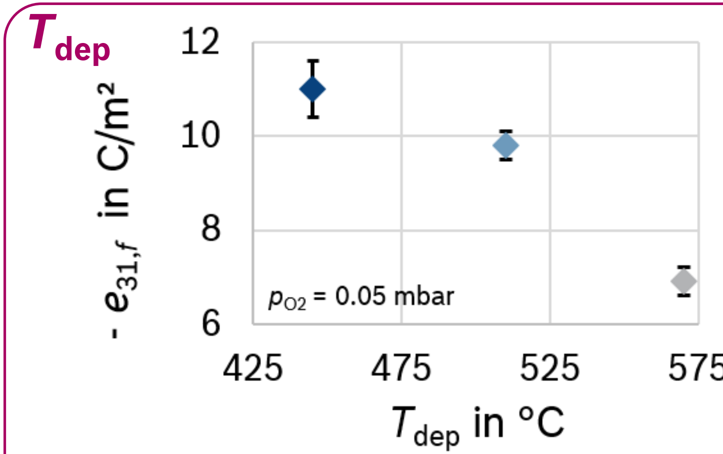
Variation of Pressure / Temperature
Piezoelectric Coefficient

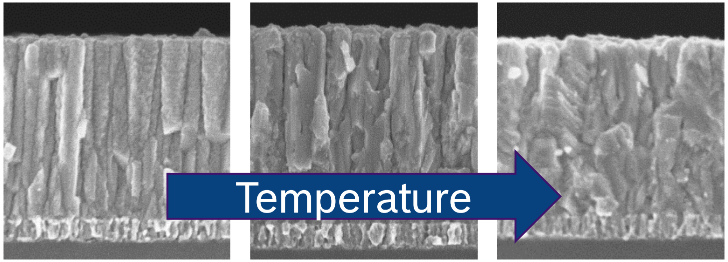
$$e_{31,f}(E_3) = -\frac{d\sigma_1}{dE_3}$$ *











The microstructure has high effect on the $e_{31,f}$. Not only crystalline phases but also grain boundaries play a major role.

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* A. Mazzalai *et al.*, J. Microelectromech. Syst., 24 (4), 2015, pp. 831-838

Conclusion
PLD settings: high effect on PZT properties

- PZT film properties are dependent on $\boldsymbol{p}_{\mathbf{O2}}$ and $\boldsymbol{T}_{\mathbf{dep}}$
  - Microstructure: smooth columnar structure ◄► coarse grain boundaries
  - No clear trend in crystalline phases (XRD)
  - Lead content: higher for higher $\boldsymbol{p}_{\mathbf{O2}}$ and lower $\boldsymbol{T}_{\mathbf{dep}}$
  - Extrinsic contribution to the permittivity (mobility of the domains dependent on the microstructure)

- Piezoelectric coefficient $e_{31,f}$: no linear correlation to $\boldsymbol{p}_{\mathbf{O2}}$ and $\boldsymbol{T}_{\mathbf{dep}}$
  - Additional factors (e.g. lead content) besides crystalline phases need to be used as indicator for high $e_{31,f}$
  - Combinations of $\boldsymbol{p}_{\mathbf{O2}}$ and $\boldsymbol{T}_{\mathbf{dep}}$ with other deposition settings (laser energy, laser spot size, ...) result in even higher $-e_{31,f}$ of >14 C/m² (not shown here)

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THANK YOU