Oerlikon PVD production solution for in-situ large scale deposition of PZT

2nd International Workshop on Piezoelectric MEMS
Materials - Processes - Tools - Devices

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Agenda

- piezoVolume project
- Sputter equipment
- Key hardware factors
- Results of in-situ PZT deposition process
- Summary and outlook

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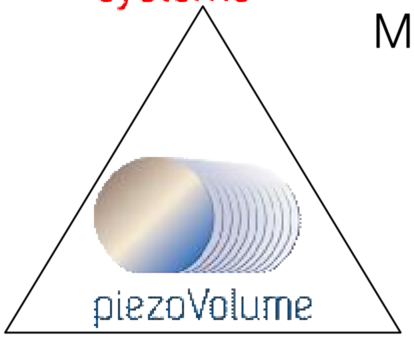
EU project "piezoVolume"
Sputter cooperation and goals

oerlikon
systems

F. Tyholdt - 14:00
FP7 piezoVolume



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systems

Development of automated high volume sputter system

M. Kratzer, L. Castaldi and B. Heinz

Fraunhofer
ISIT

Process development

D. Kaden and H.J. Quenzer

EPFL
ÉCOLE POLYTECHNIQUE FÉDÉRALE DE LAUSANNE

Process development

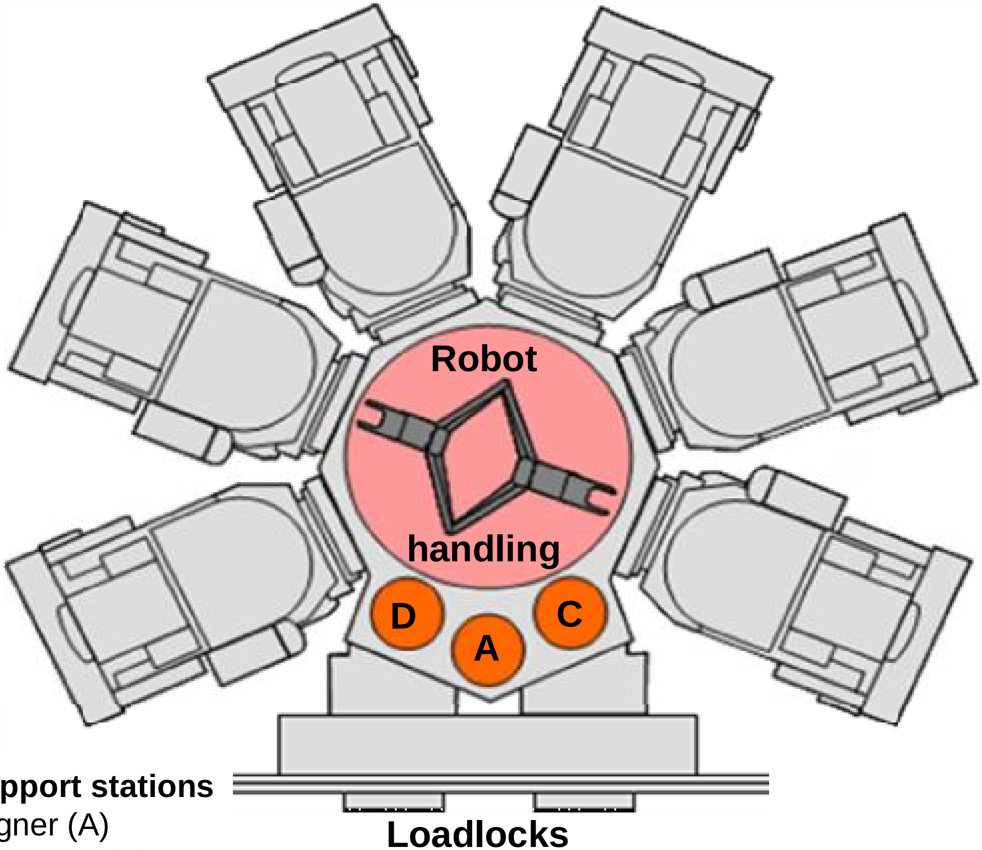
A. Mazzalai, S. Harada and P. Muralt

Overview	Goal of this cooperation is to develop <u>in-situ</u> PZT processes on a Oerlikon sputter system which meet commercial production requirements
Project goals	High quality PZT films on 8" substrates § Dielectric constant ~ 1200 and dielectric loss tanδ < 0.03 § Piezoelectric coefficients $d_{33,f}$ > 100pm/V and - $e_{31,f}$ > 14 C/m2 § Thickness uniformity < ± 5% at max. thickness 4 - 5 µm § Throughput > 3.6 wafer/hr·µm (= 1nm/s)

Equipment for PZT in-situ sputtering

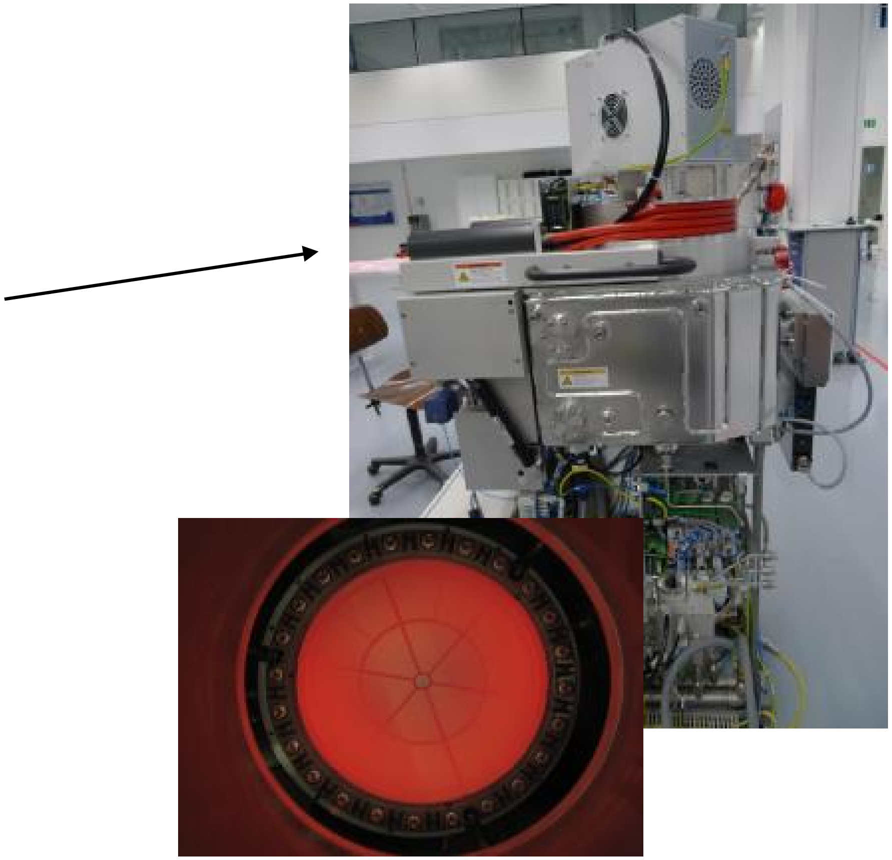
RF magnetron sputtering from single ceramic target

CLN200 sputter tool



Support stations
Aligner (A)
Degasser (D)
Cooler (C)

RF sputter module equipped with
8” Very Hot Chuck



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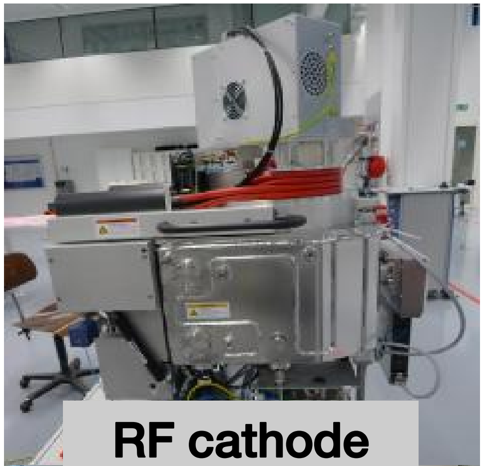
Key hardware factors

Overview

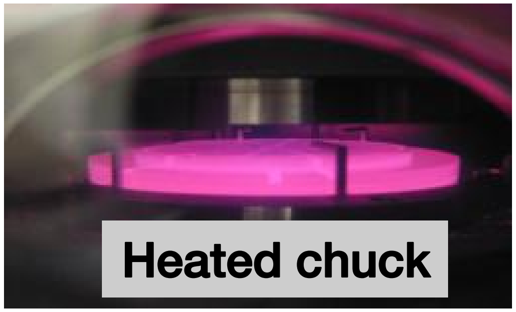
Anode & Shieldings

PZT sputter equipment



RF cathode

RF Bias & master oscillator



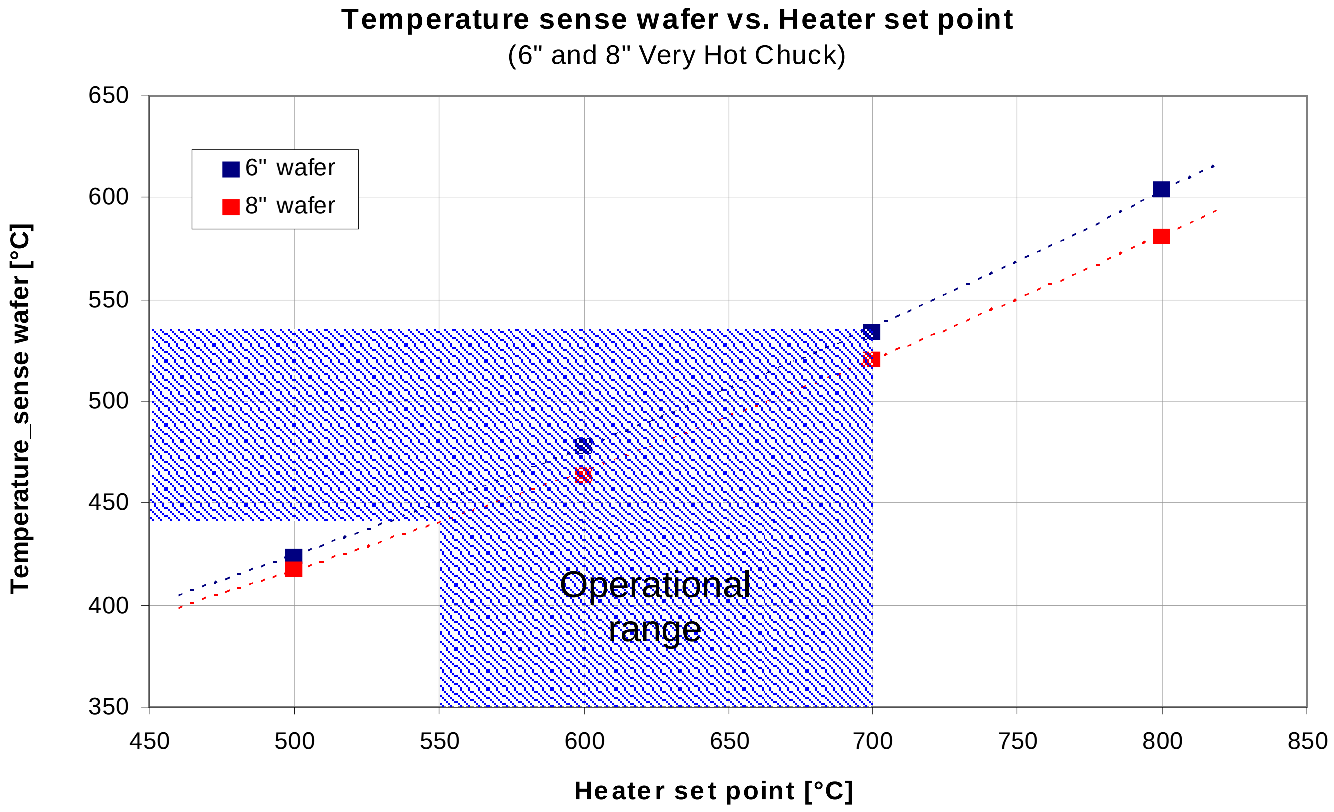
Heated chuck

Magnet array & Target

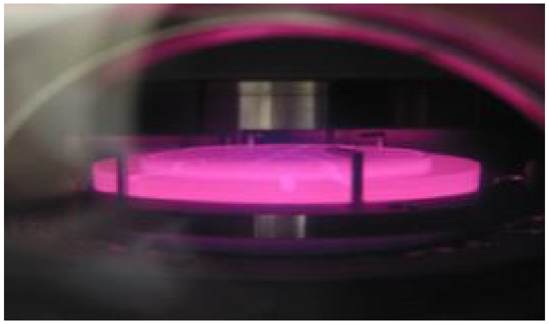
Key hardware factors

Very Hot Chuck

Heated substrate holder for 6” and 8” wafer enable deposition process in the temperature range needed for in-situ sputtered PZT films



6” Very Hot Chuck



8” Very Hot Chuck

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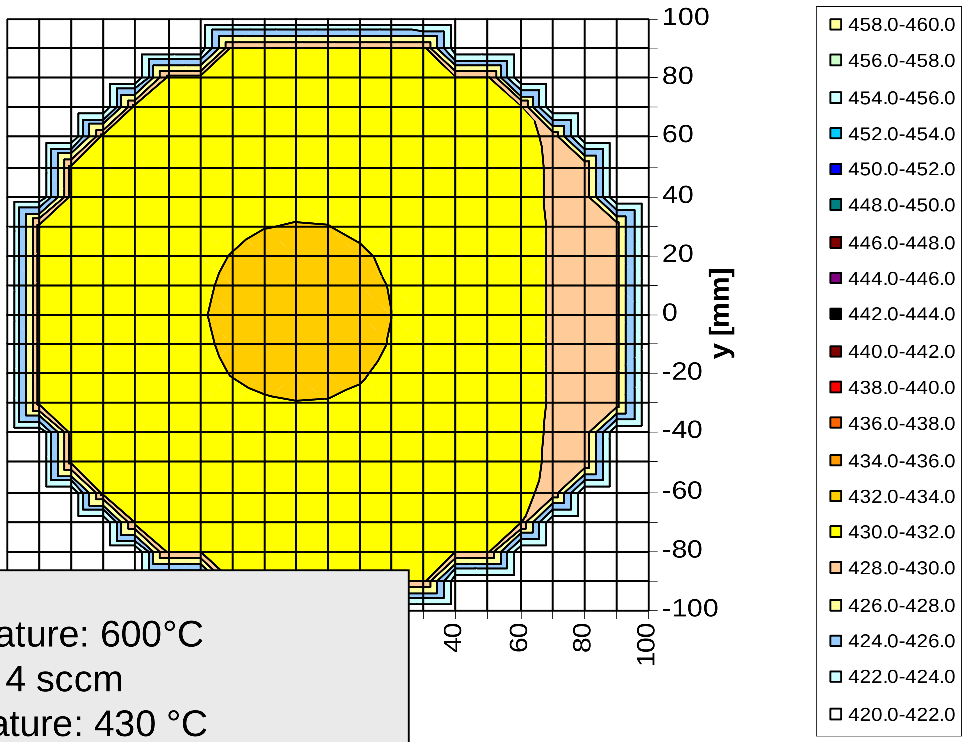
Key hardware factors
Temperature uniformity 8” Very Hot Chuck

Optimization of process settings to achieve highest wafer temperatures and excellent temperature uniformity by

- Back gas flow
- ID / OD heating (Alpha factor)

Temperature uniformity



Chuck temperature: 600°C
Backside gas: 4 sccm
Wafer temperature: 430 °C

Measurement Statistics	
Uniformity	2.44%
Mean	430.76 [°C]
Range	10.50 [°C]
Max	434.70 [°C]
Min	424.20 [°C]

8” Very Hot Chuck

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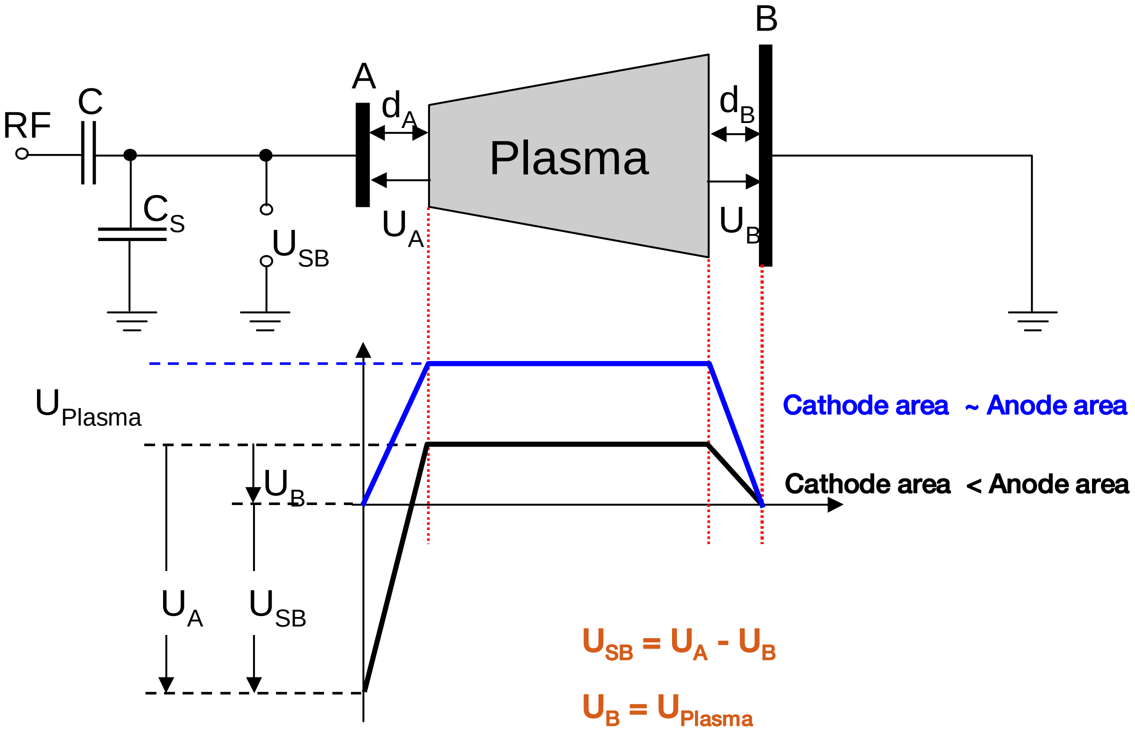
Key hardware factors

RF target self bias voltage

Target self bias voltage influenced by

- Process pressure
- RF power
- Anode area

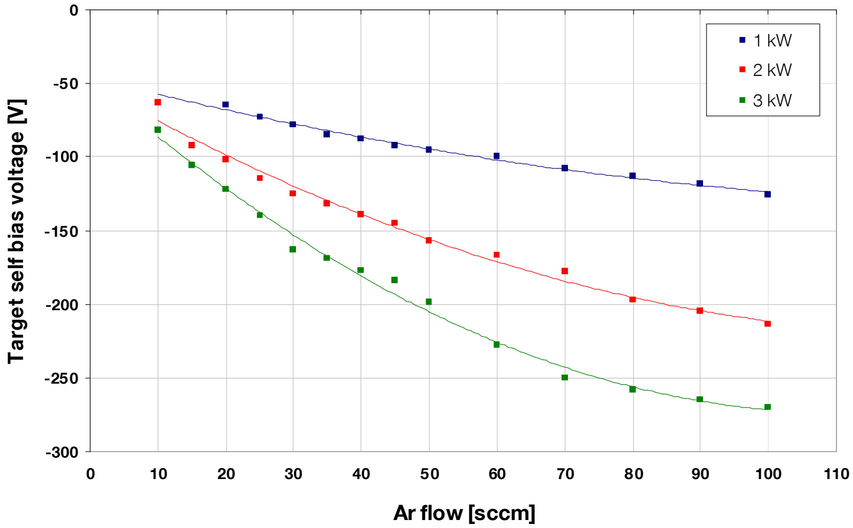


$U_{SB} = U_A - U_B$

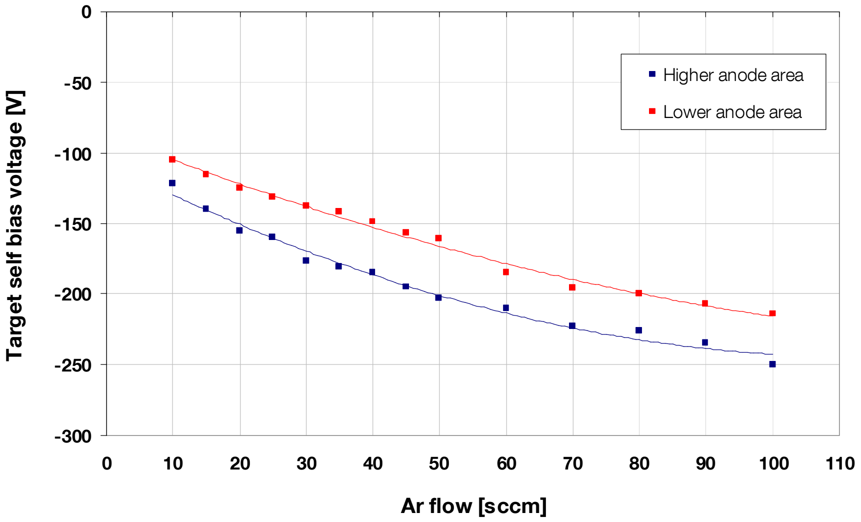
$U_B = U_{Plasma}$

$U_A / U_B = (Area_B / Area_A)^n$

1. RF power



2. Anode area



Key hardware factors
Magnetron design

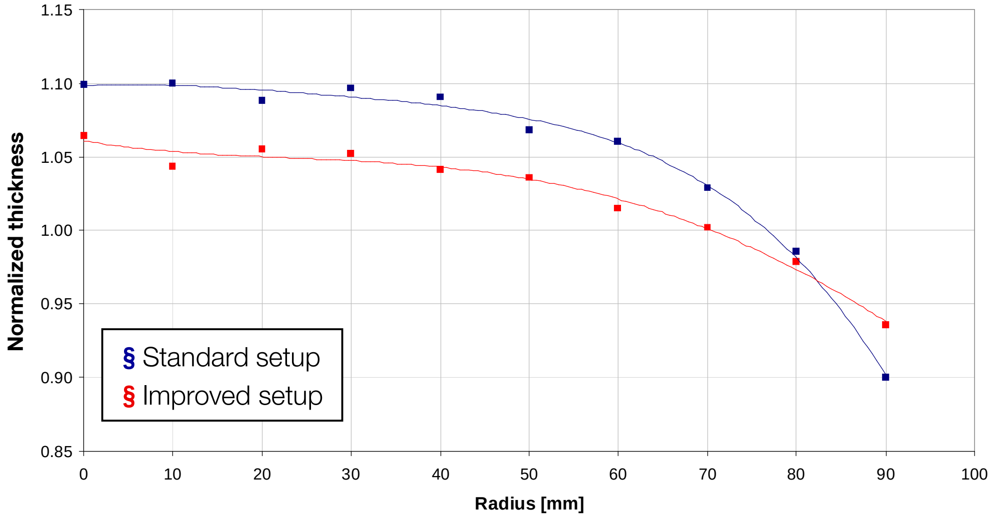
PZT thickness and composition uniformity influenced by

- Erosion profile
- Emission characteristic of sputtered atoms
- Scattering (~ pressure · distance)
- Substrate temperature

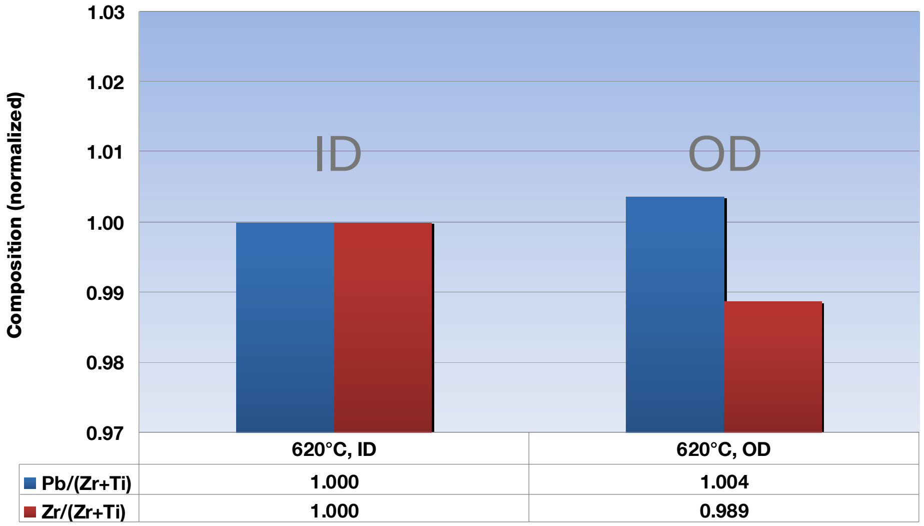
Actual sputter performance

- Deposition rate > 40 nm/min
- Estimated target life time ~ 1600 µm film thickness for 4mm target

Thickness uniformity



Composition uniformity



	620°C, ID	620°C, OD
■ Pb/(Zr+Ti)	1.000	1.004
■ Zr/(Zr+Ti)	1.000	0.989

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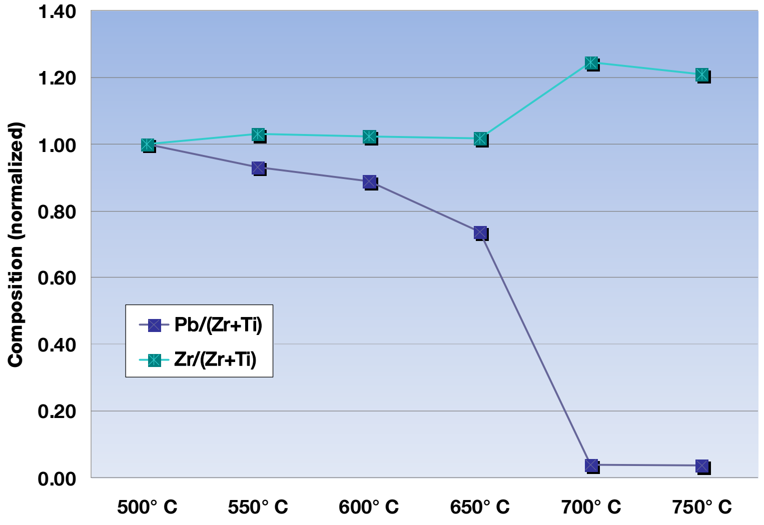
In-situ PZT deposition process
General trends

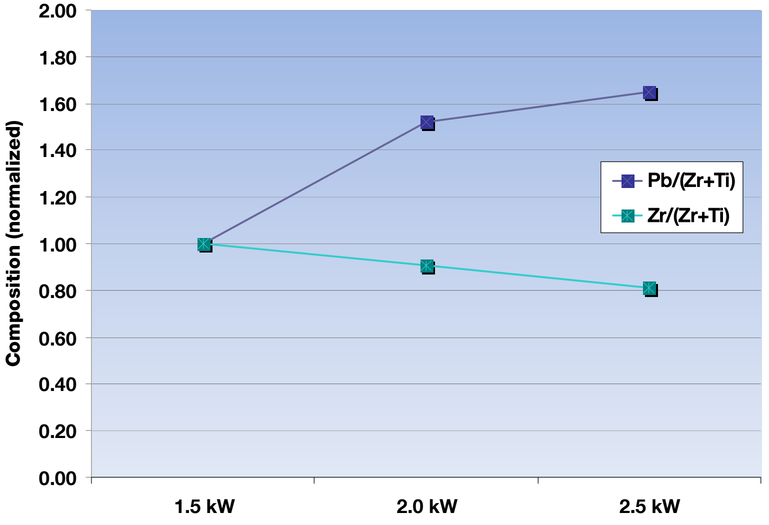
Relative Pb content can be influenced

- Pb decrease with temperature increase
- Pb decrease with Ar flow increase
- Pb increase with RF power increase

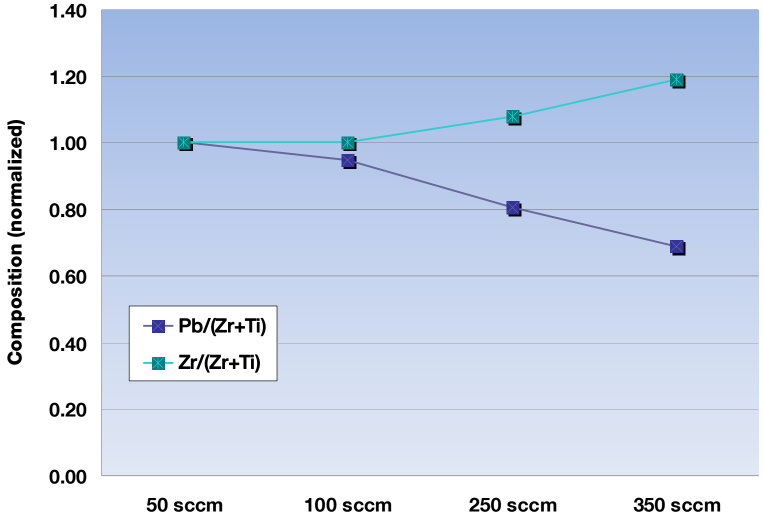
Variation of substrate temperature



Variation of RF power



Variation of Ar flow



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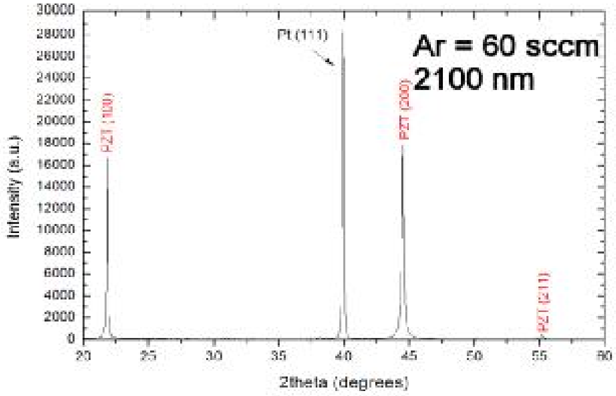
In-situ PZT deposition process

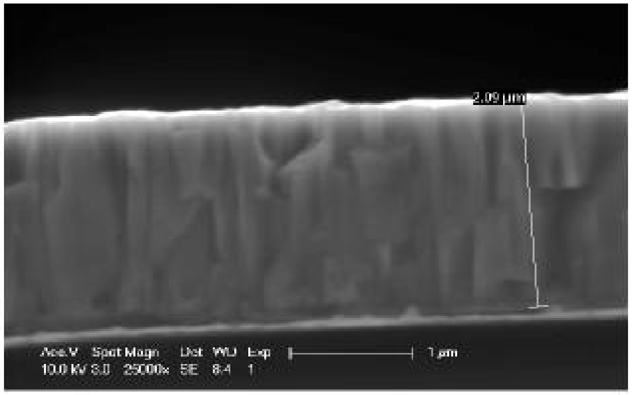
6” PZT with PTO seed layer

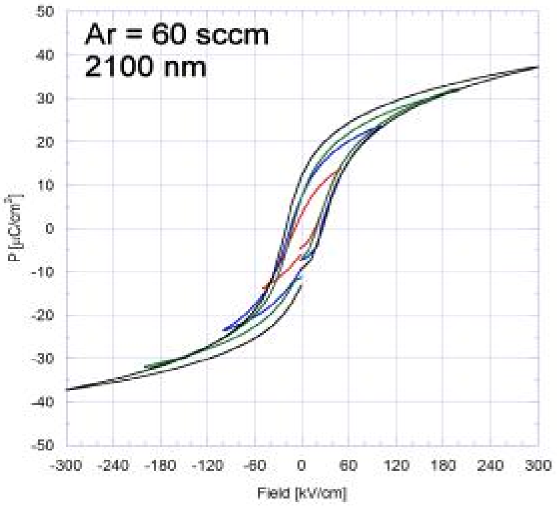
- Best PZT films achieved with a PTO seed layer to promote the nucleation of the PZT perovskite structure

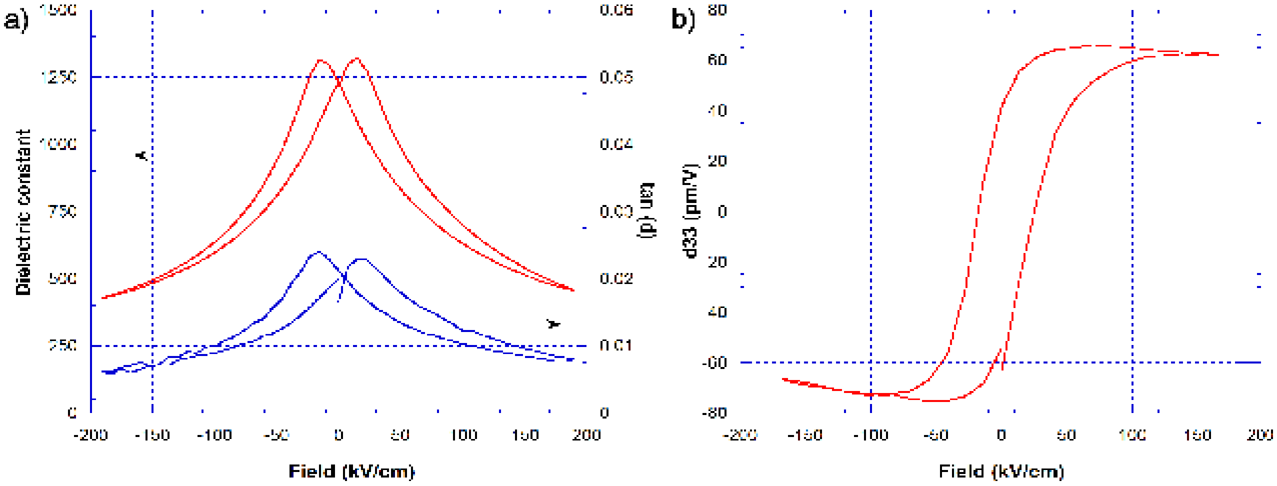
- For films sputtered at 1 kW
  - $\varepsilon \sim 1500$
  - $\tan\delta = 3.2\%$
  - $d_{33,f} = 100$ pm/V
  - $-e_{31,f} = 7.5\ \mathrm{C/m^2}$

Performance of films deposited at 2 kW





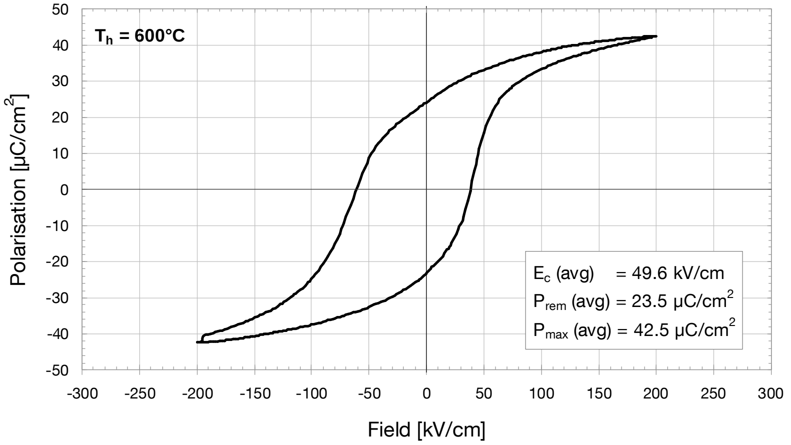


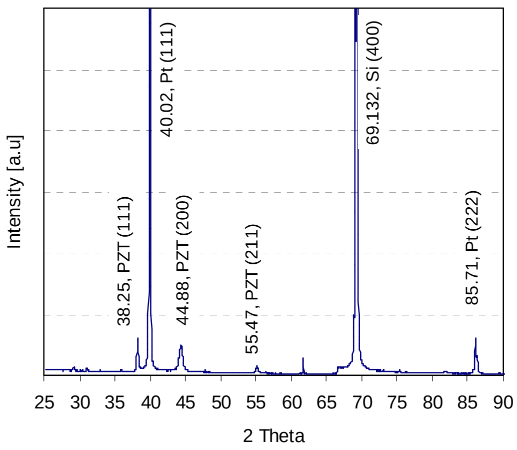


In-situ PZT deposition process

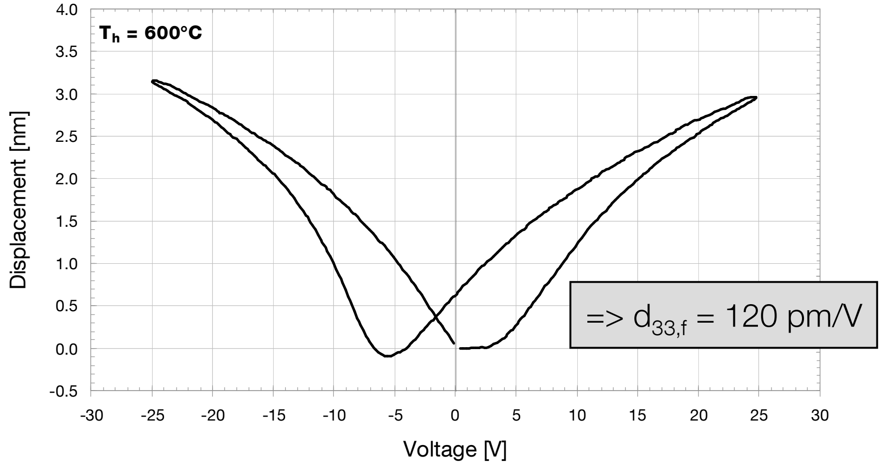
8” PZT with TiO_2 seed layer

- Best piezoelectric data
  - $\varepsilon \sim 1200$
  - $\tan\delta = 3\%$
  - $d_{33,f} = 120$ pm/V
  - $-e_{31,f} = 12.6$ C/m^2
- Similar performance for films without TiO_2 seed layer

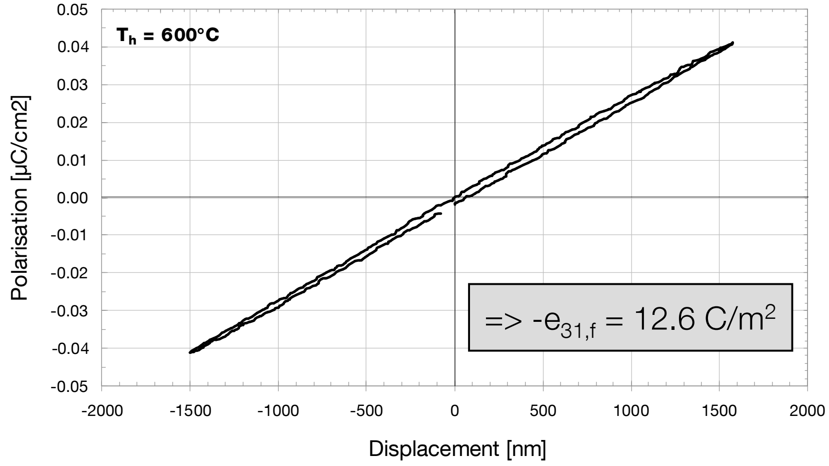




Displacement vs. voltage



Polarisation vs. displacement



In-situ PZT deposition process
Summary

- The existing sputter equipment is capable to deposit PZT films in-situ with the required perovskite structure

- Therefore no additional annealing step is needed in the process sequence

- Electrodes and PZT films can be deposited consecutively in a cluster tool without breaking the vacuum

- Piezoelectric performance of best films comparable to state-of-the-art films deposited by chemical solution deposition (CSD)

- Further improvements achievable by
    - Magnetron design => Thickness and composition uniformity, deposition rate
    - Target properties => Deposition rate
    - Process optimization => Piezoelectric properties

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COOPERATION

Thank you for your attention