Oerlikon PVD production solutions for piezoelectric materials

Workshop PiezoMEMS
Aachen,18. /19.05.2010

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Oerlikon company and products

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- **Oerlikon Solar** — oerlikon solar
- **Oerlikon Coating** — oerlikon balzers
- **Oerlikon Vacuum** — oerlikon leybold vacuum
- **Oerlikon Textile** — oerlikon barmag; oerlikon neumag; oerlikon saurer; oerlikon schlafhorst; oerlikon textile components
- **Oerlikon Drive Systems** — oerlikon graziano; oerlikon fairfield
- **Oerlikon Advanced Technologies** — oerlikon systems

The Oerlikon group is one of the most innovative industrial groups in the world.

We are active in various markets around the world, machine and plant engineering, solar technology, thin film coating, vacuum systems, textile machines, drive systems and nano technology.

With over **16,000 employees** at **158** sites in **37 countries**, we develop solutions for leading industry applications and future-oriented markets.

Piezo AlN & ZnO for MEMS

- Excellent crystalline quality and piezoelectric performance
- Patented thickness uniformity control (Flexicat)
- Stress adjustment using HF chuck bias, excellent stress uniformity
- Electrode and seed technology
- CLN flexibility

In situ growth of PZT

- RF sputter technology for $Pb(Zr_{x},Ti_{1-x})O_3$ deposition from ceramic target
- Very Hot Chuck (T>800°C)
- Direct growth of the piezo-electric perovskite phase
- No post annealing needed
- Substrate size up to 200mm
- Electrode technology

Semiconductors

Optical Disc

Advanced Nanotechnology

	Semiconductors	Optical Disc	Advanced Nanotechnology
PRODUCTS	CLUSTERLINE 200/300 LLS	Sprinter, Swivel, CubeStar	Solaris for Photovoltaics
APPLICATIONS	Adv/3D Packaging Thin Wafer & Multi Level Vias Thin Film Heads MEMS, NEMS Compound Semi	Blu Ray Media All DVD formats	Thermoelectrical generators Thin film batteries Touch Panels Fuel Cells
STRATEGY	Focus on selective markets	Focus Blu-Ray	Clean Technology

Thin films used for SAW, BAW, MEMS, etc.

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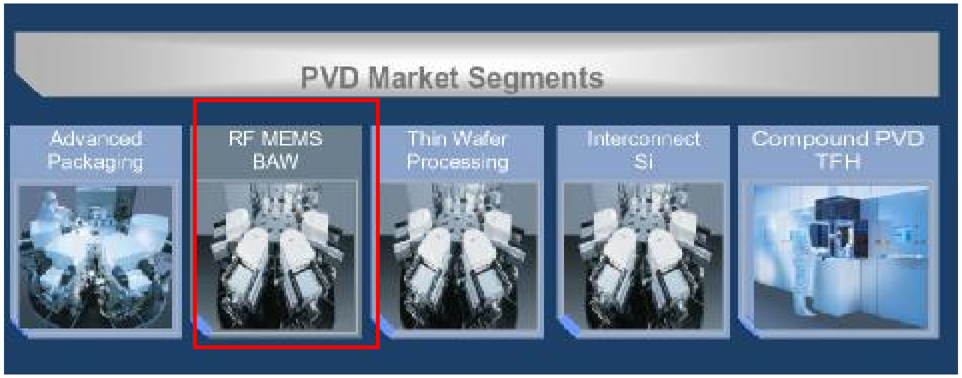


Piezoelectric Thin Films **Solidly Mounted Resonator, Film Bulk Acoustic Resonator, Thin Film Surface Acoustic Wave, p-MEMS sensing and actuating, RF-MEMS, bio-sensing, etc...**	**p-AlN, p-ZnO, p-PZT**
Dielectric Thin Films **SMR Acoustic Reflectors, Temperature Compensation Layer for SAW or BAW, Ultra-thin Passivation for SAW, Passivation, RF-MEMS switches, SMR & FBAR Shunting &Trimming Layers, embedded passives** **inkjet printing...**	**AlN, ZnO, SiO_2, Ta_2O_5, TiO_2, (PZT) ...**
Metal Thin Films **SMR Acoustic Reflectors, Bottom and Top SMR & FBAR electrodes, SAW Electrodes, MEMS Metallizations, ...**	**Al, AlCu, AlSi, W, Ti, Pt, Mo, Ir, ...**
Resistor films **Integrated Resistors, Heater Elements (ink-jet)**	**TiW-N, TaAl-N**

AlN application - Bulk Acoustic Wave Filter

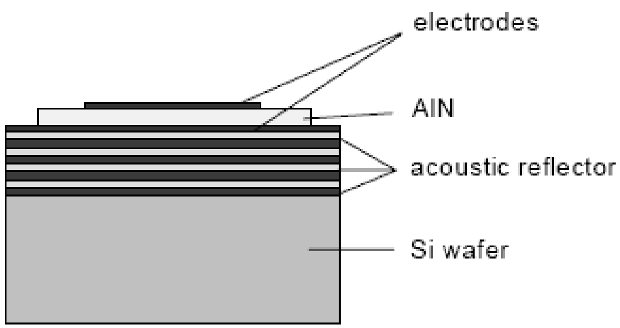


Figure 2: Schematic view of a solidly mounted resonator (SMR).

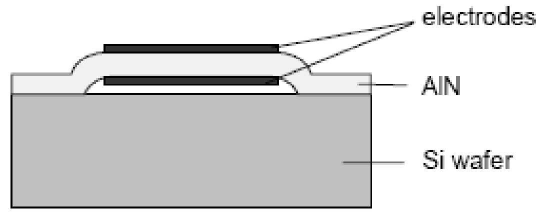


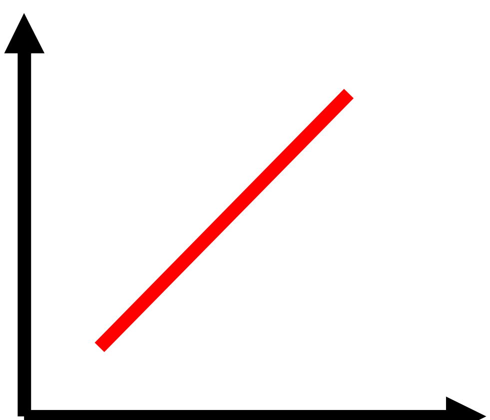
Figure 1: Schematic view of a film bulk acoustic resonator (FBAR).

At mechanical resonance:
$d_{AlN} = \lambda / 2$
$f_R = v / \lambda = v / 2d_{AlN}$

for f_R = 2.1GHz and v = 11300m/s
=> $d_{AlN} \sim 2\mu m$

Figure of merit (FOM) of BAW resonator

FOM = $kt^2 * Q$



AlN film quality

Requirements for high AlN electro-mechanical coupling and quality factor

- Excellent thickness uniformity
- Excellent AlN texture and c-axis orientation
- Low stress of single film and film stack
- Smooth film surfaces to avoid acoustic scattering
- Precise temperature control during deposition
- Low oxygen incorporation (high base vacuum, low leak rate)

Oerlikon production solution for AlN

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- AlN deposited by DC pulsed reactive PVD process
- High quality of film achieved with advanced features of sputter equipment

  => High throughput and yield with constant quality

Sputter equipment

- Vacuum performance
- Design of gas inlet
- Magnetron design
- Heater design
- RF bias capability
- Flexible sputter configurations (Formats, TS)
- Advanced features (e.g. Flexicat)

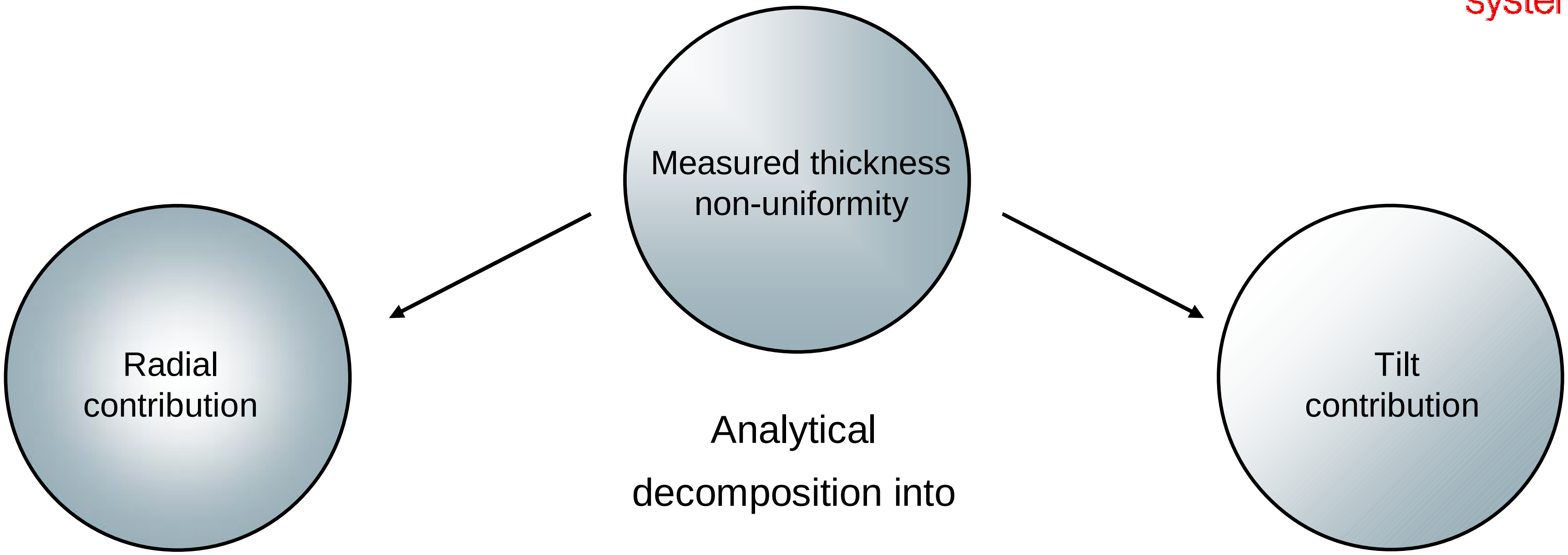
Process parameter

- Deposition temperature
- DC power
- RF bias
- N_2 and Ar flows
- Target-to-substrate distance
- Pulse frequency
- Pulse duty cycle

Film properties

- Thickness uniformity
- Film stress
- Texture / c-axis orientation
- Surface roughness

Thickness uniformity



Flexible solution needed

- Target erosion over life time
- Process settings (e.g. gas pressure)
- Sputter geometry (TS)

- Target homogeneity
- Pumping geometry
- Design of gas inlet
- Mechanics

Oerlikon FlexiCat

- **Movable positions of inner magnets**
- **Synchronized power modulation with magnet rotation**

Target Erosion compensation with FlexiCat

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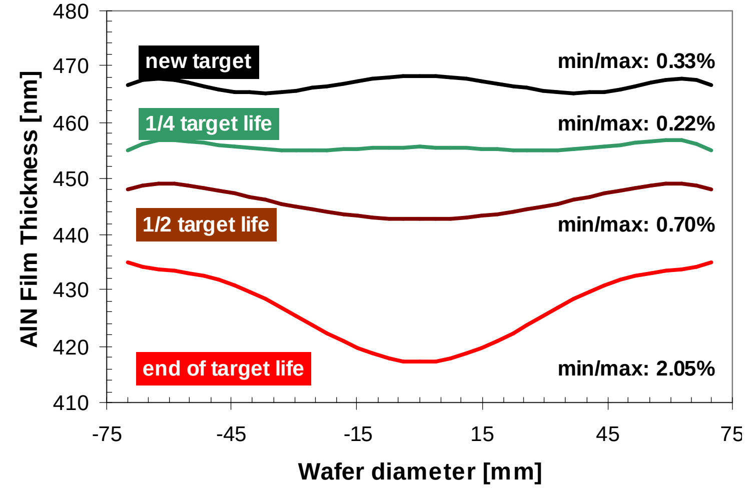
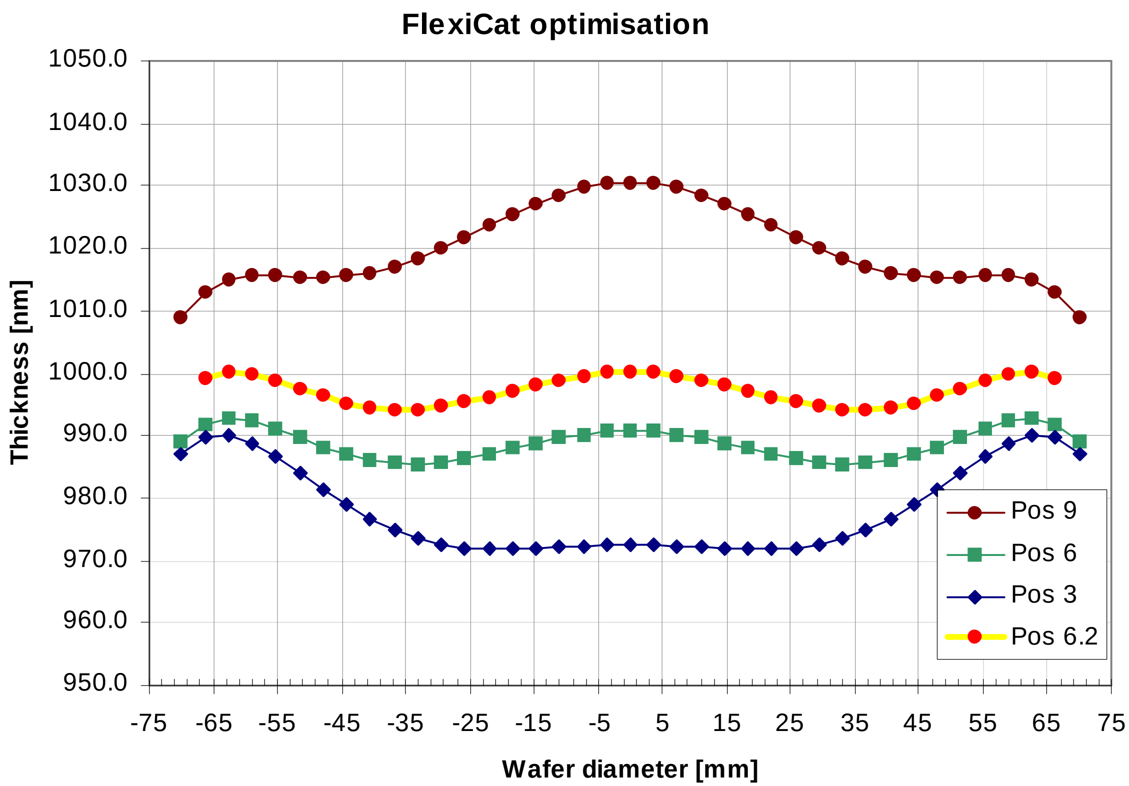
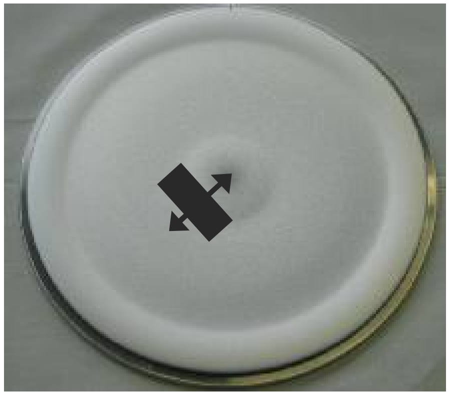
- Thickness uniformity increases over target life with fixed magnetic system → effect of target erosion
- Effect can be compensated by FlexiCat radial adjustment of inner magnets

Thickness uniformity over target life



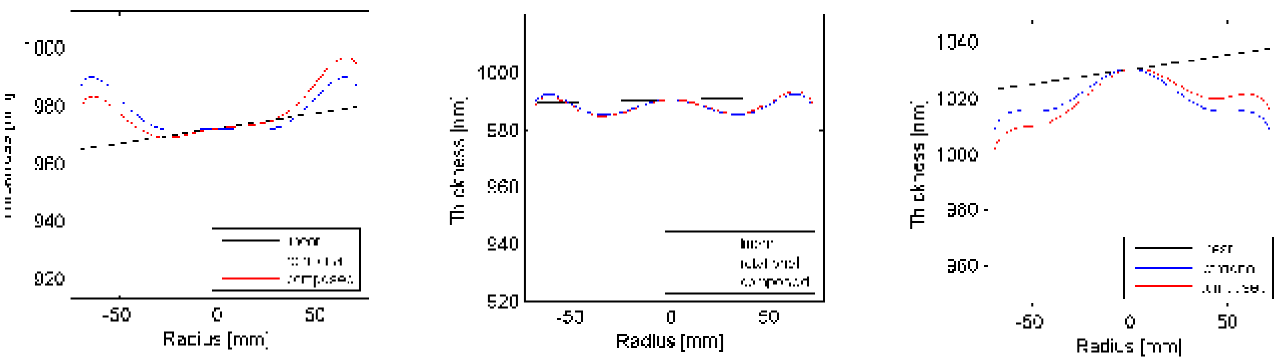
Example for radial compensation



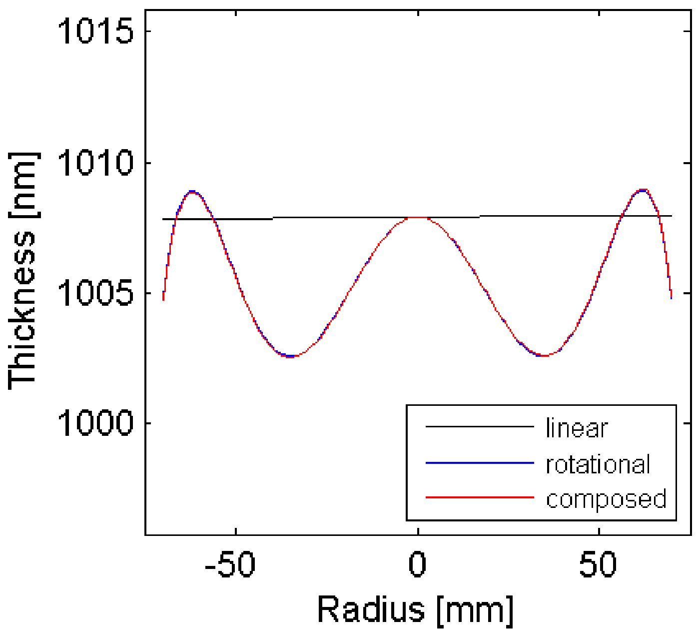


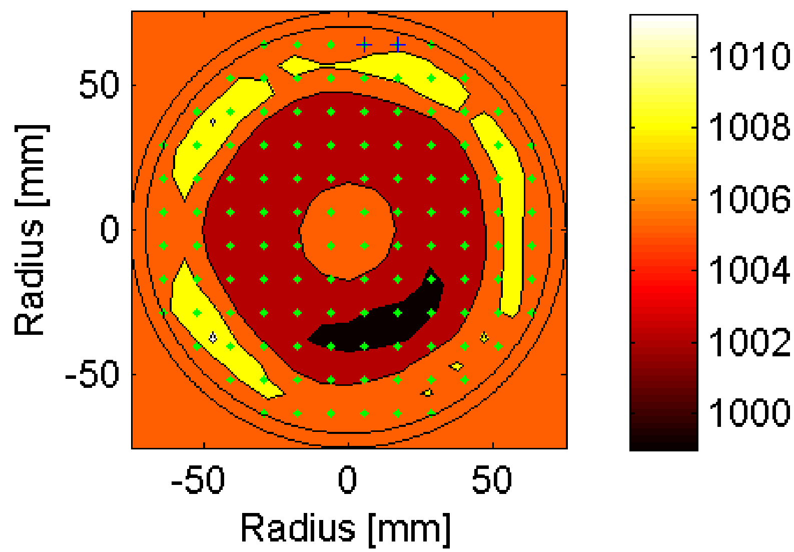
Movable position of inner magnets

Tilt compensation with FlexiCat



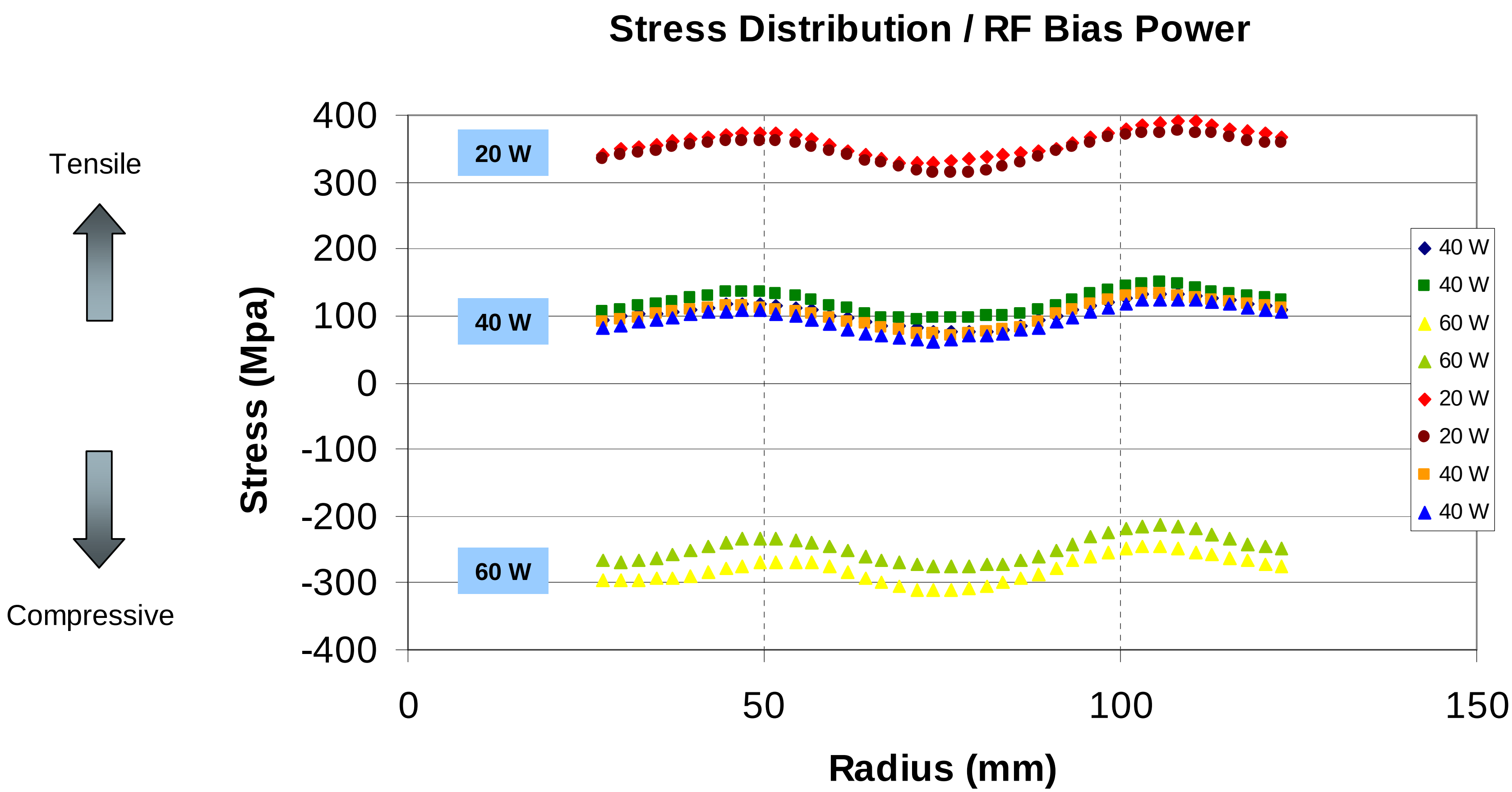
- Calculation of compensation parameters from thickness measurement at 3 different settings
- Control of magnet position and power synchronization with CL200 recipe software





Stress control through substrate RF bias

- Applying RF bias to substrate lead to adjustable negative bias voltage
- Adjustable flux of ions with variable energy
- Deposition rate, thickness uniformity remains unchanged by RF Bias adjustment



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Crystal orientation (c-axis)

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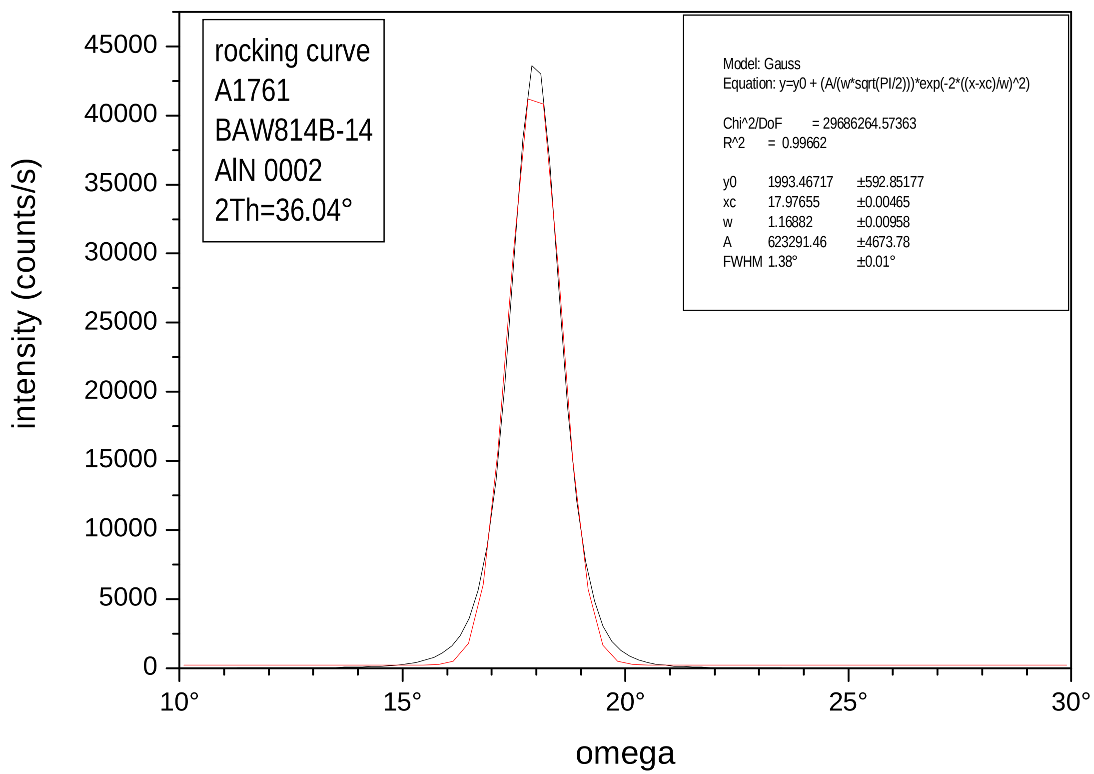
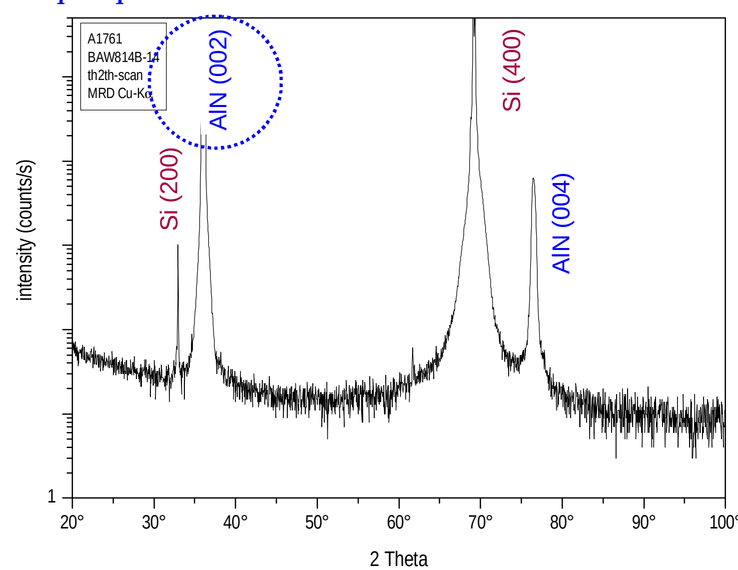
- Electrode surface microstructure and roughness key to high c-axis textured AlN
- Optimization of highly textured Mo(110), Al(111), W(110), Pt(111) and Ti(002)
- Ti or AlN seed layer beneficial for improving electrode texture and smoothness

Rocking curve - AlN (002)



q-2q scan AlN on Si substrate



<u>Result for wafer BAW814-14</u>

Pure AlN 002 on θ-2θ

1.38° AlN 002 rocking curve FWHM

Piezoelectric performance

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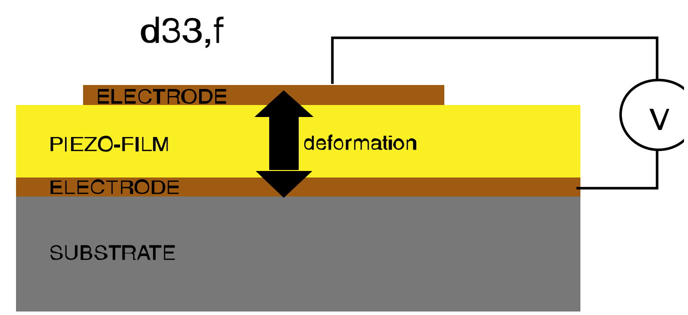
- Inverse Piezoelectric Coefficient d33,f of 2µm AlN
- Measured by Double Beam Interferometry at external institutes

	$d_{33,f}$ [pm/V]		XRD RC AlN 002
Wafer #1 **(sw01)**			
Institute A	5.2	0.2 (σ)	
Institute B	5.8	0.5 (±)	1.32°
Wafer #2 **(sw08)**			
Institute A	5.2	0.6 (σ)	
Institute B	5.2	0.5 (±)	1.23°



- d33,f on Mo electrodes > 5.10 pm/V @ 2mm AlN film thickness
- d33,f results comparable to best values published for AlN on Pt electrodes (*) showing the very high quality of the AlN films
- Electro-mechanical coupling coefficient BAW: k2>6.2%

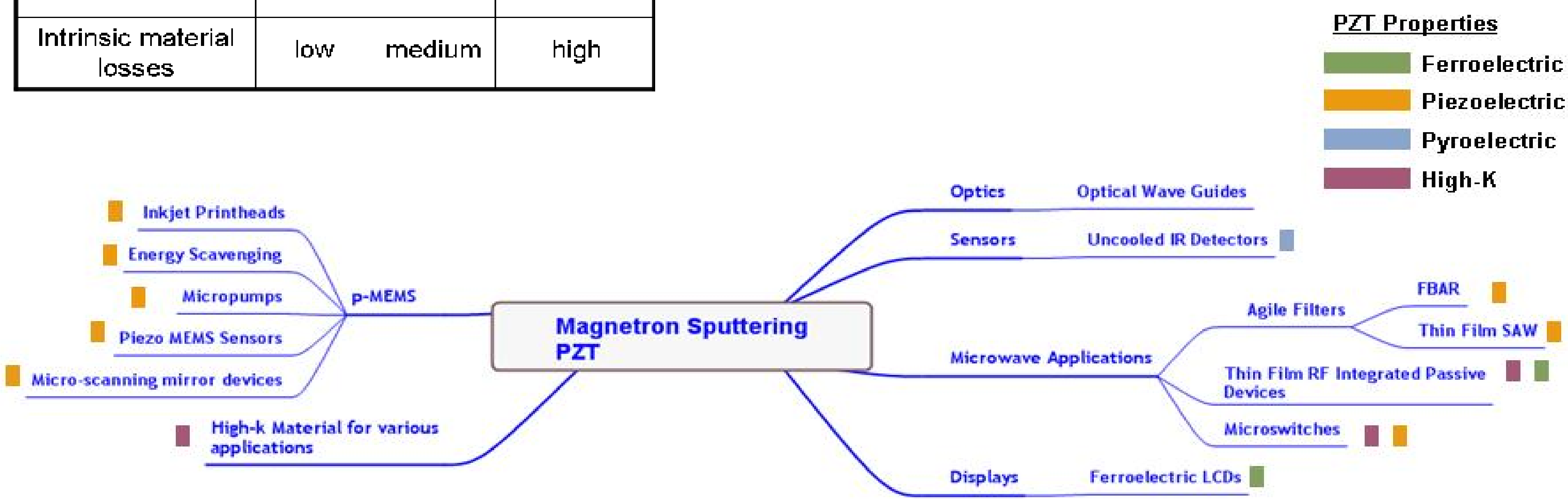
(*) "Is there a better material for thin film BAW applications than AlN?", P. Muralt et al., IEEE Ultrason. Symp. 2005

Sputtered PZT - Potential Applications Map

Comparison AlN - ZnO - PZT

	AlN	ZnO	PZT
Coupling coefficient k_t^2 (%)	6 - 7	7.5	20 - 30
Dielectric constant ε_r	10	9.2	100 - 500
Sound velocity	10400	6350	4000-6000
Intrinsic material losses	low	medium	high

main driver for growing interest in **perovskite textured PZT films**



Competing Deposition Methods for PZT

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- **In-situ sputtering from single target**
  - Higher quality possible compared to post anneal process
  - Wafer temperatures > 550°C needed during deposition
  - RF sputtering from ceramic target
  - Oerlikon approach since 2008

- **Sputter process with post anneal step**
  - Additional process step compared to in-situ growth
  - Danger of inhomogeneous phase transformation during RTP with the risk of pore formation and irregular grain shape
  - Oerlikon: PZT deposition followed by RTP process at customer (2003)

- **Chemical Solution Deposition (CSD)**
  - Competing technology, similar to photo resist application

Ferroelectric / Dielectric Data for PZT with 450°C Process & Post Anneal

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Achieved film properties

1. Strong (111) perovskite texture
2. Remanent polarization ~ 28 µC/cm^2
3. Coercive Field ~ 80 kV/cm
4. Typical rel. dielectric constant ~1000
5. Deposition rate: 2.5A/Sec

Guideline for development of the in situ process :

Baseline PZT film specs for 2-3µm coatings on platinized wafers:

- Composition: $Pb(Zr_{0.52}Ti_{0.48})O_3$
- Remanent polarization > 15µCcm^{-2}
- Dielectric constant: ε_r~1200
- Deposition Rate at 600°C: 0.5-1nm/s
- Piezoelectric coefficient: $d_{33,f}$ > 100pm/V
  - $e_{31,f}$ > 14C/m^2

The below table illustrates a set of values from a similar PZT film with a different process

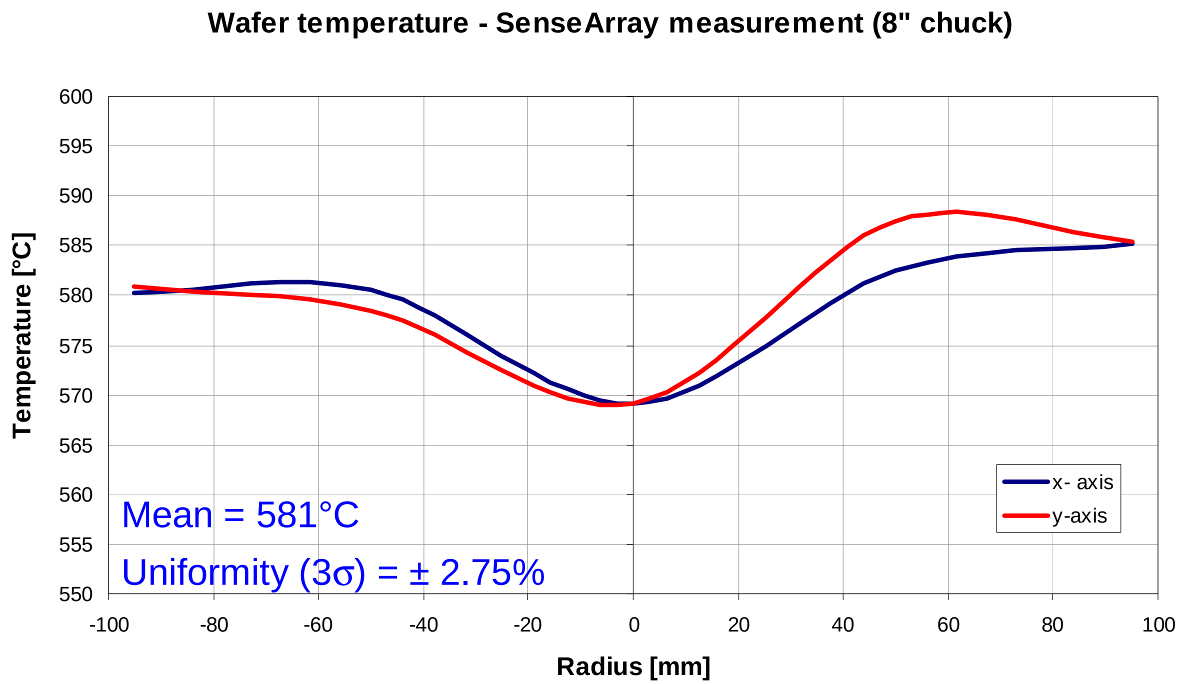
P_r (µC/cm^2)	E_c (kV/cm)	k	tan δ	Thickness [Å]	Uniformity [±%]	Composition Zr/Ti	Piezoelectric coefficient d33,f [pm/V]
19.0	26.5	995	**0.015**	10050	**0.80**	**0.93**	**> 60**

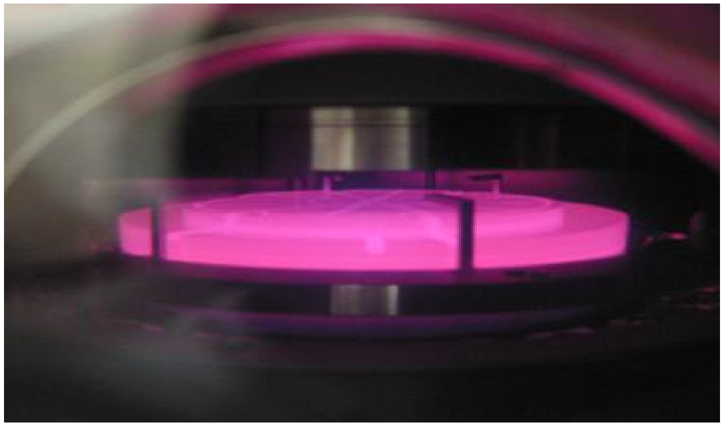
Oerlikon Systems, 17.05.2010, M. Kratzer, R&D, e-mail: martin.kratzer@oerlikon.com

Hardware Development for PZT sputtering

Very high temperature chuck for in-situ growth of PZT

- Wafer temperatures in a range of 600 - 650°C achieved with a chuck temperature setpoint of 800°C
- Excellent temperature uniformity
- Chuck is capable for wafer sizes up to 200mm





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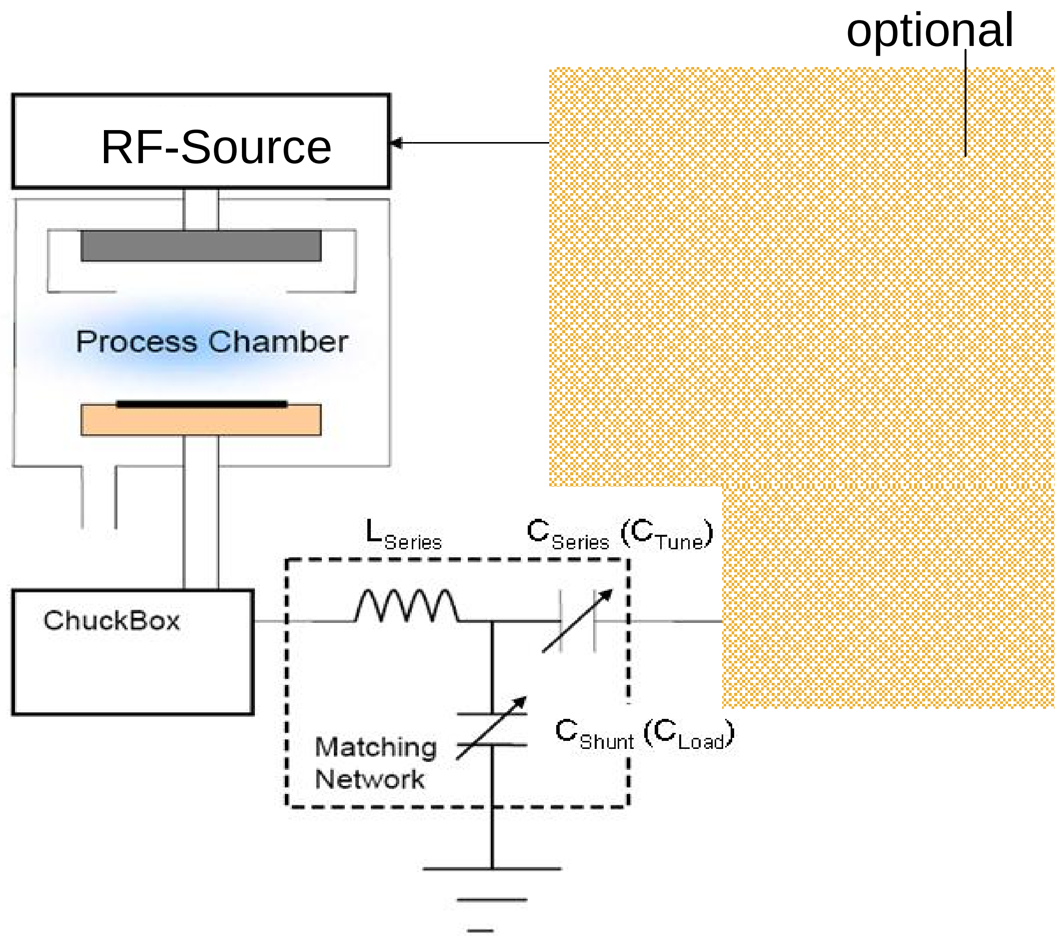
Hardware Development for PZT sputtering

RF sputtering

- Enlarged process window with stacked anode concept
- Large range for sputtering process 2 – 10 mtorr
- Adjustment of substrate / chuck bias with passive and / or active components
- To avoid stray protection of materials with low melting point (e.g. Pb) in chamber additional shielding is used



Radial uniformity vs. chuck bias voltage

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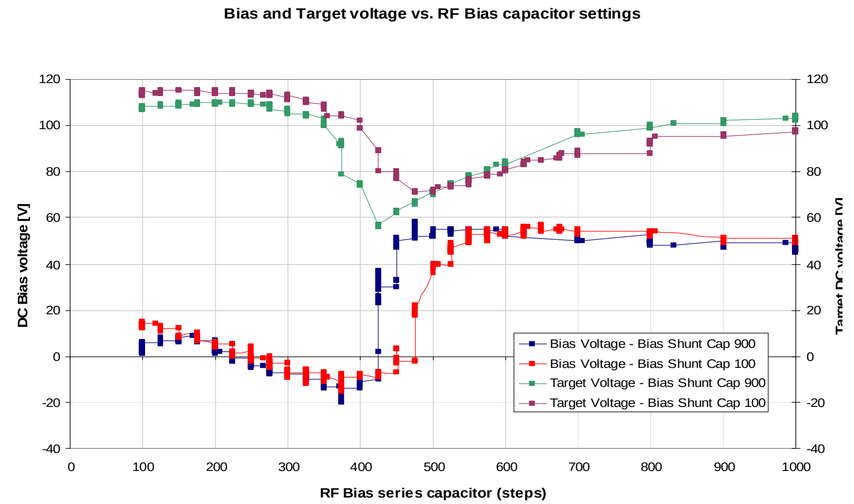
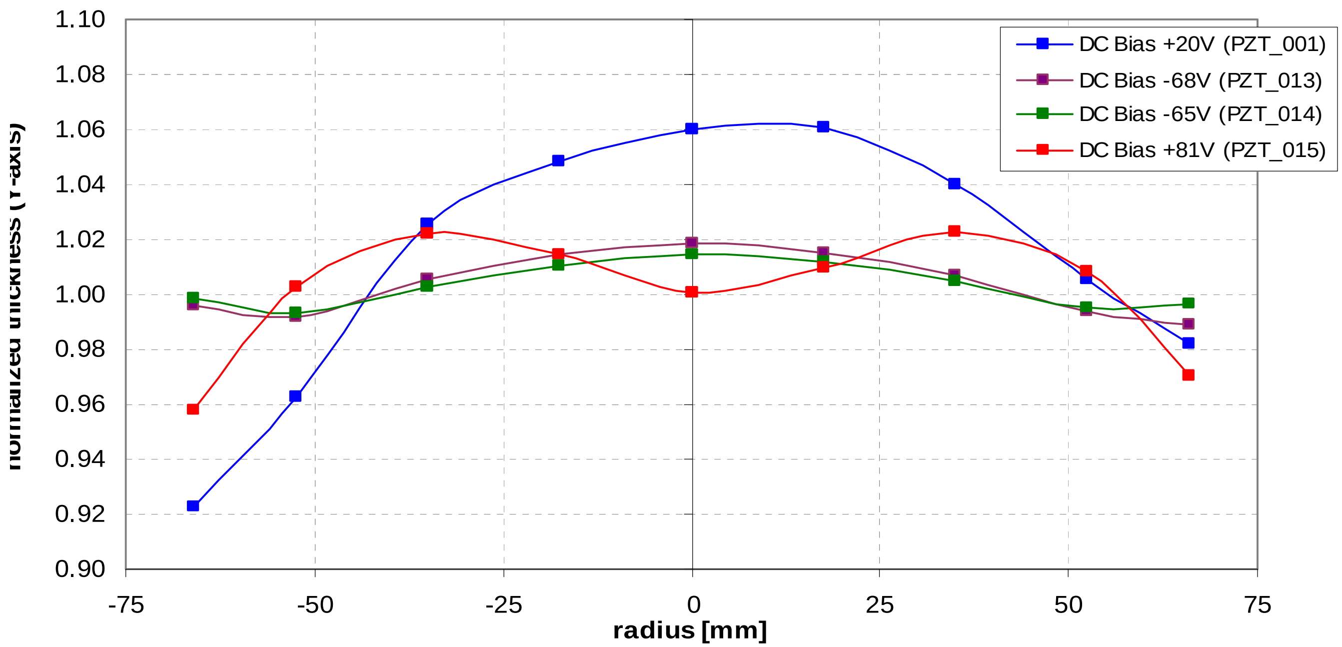
- Variation substrate bias / target voltage by RF Bias capacitor settings (substrate tuning)

=> Radial uniformity changed



Uniformity PZT vs. DC Bias voltage

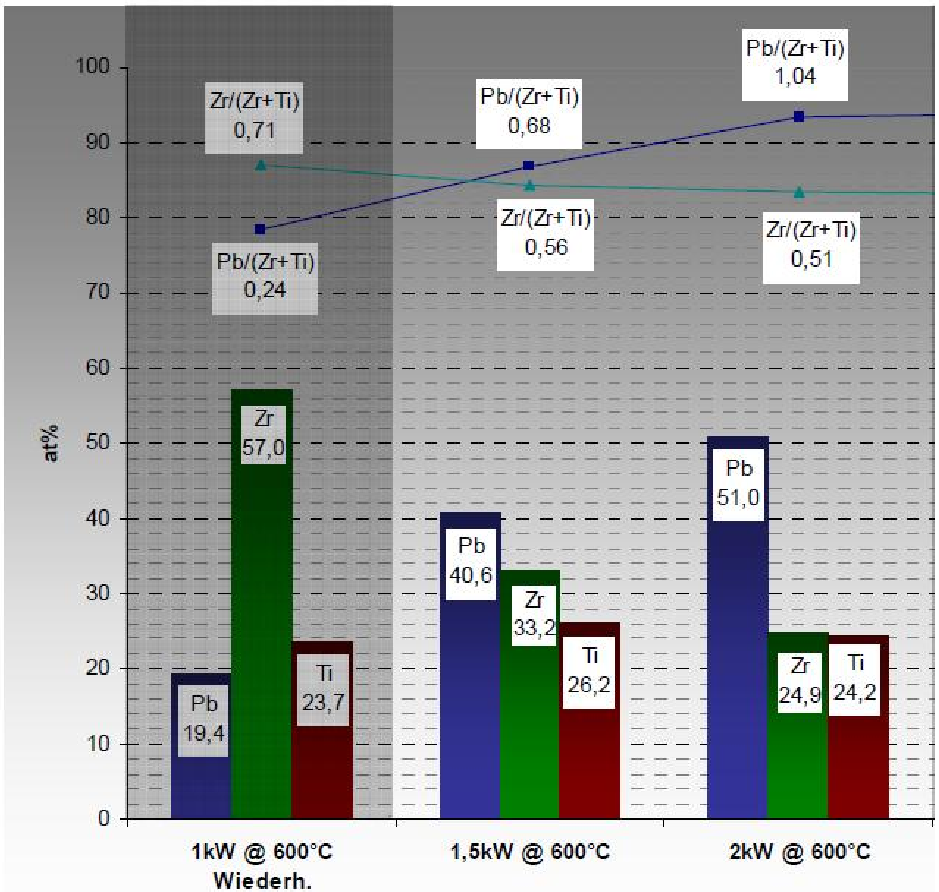
(MB300 HA, 3kW, 20sccm Ar only, Std. anode stack, TS80, ISIT P6)



Dirk Kaden, Michael Kern
Fraunhofer Institut ISIT
April 2009

In situ growth of PZT
Process Result

- Compositional analysis (EDX) of in-situ sputtered PZT films at different power settings



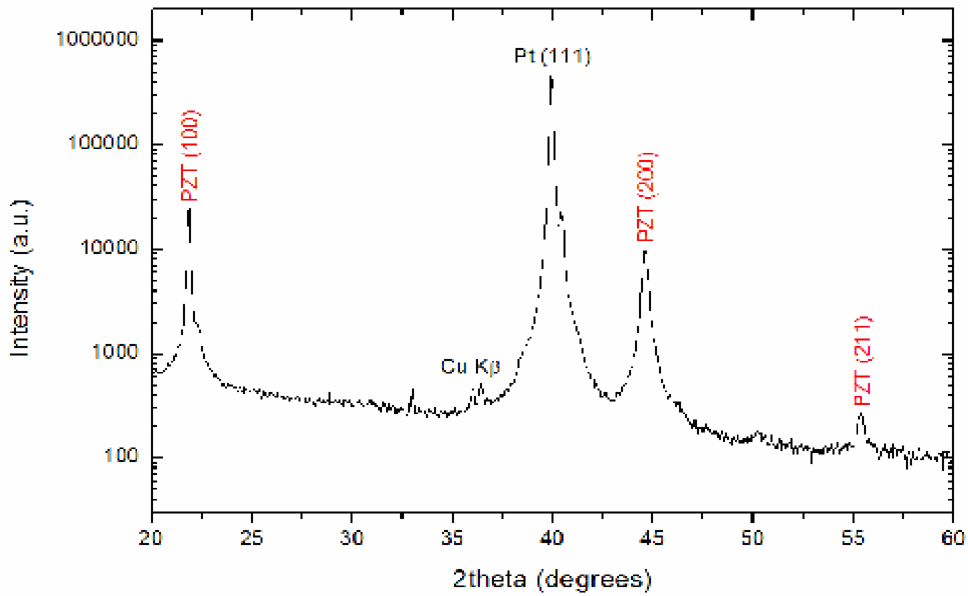
RF sputter power

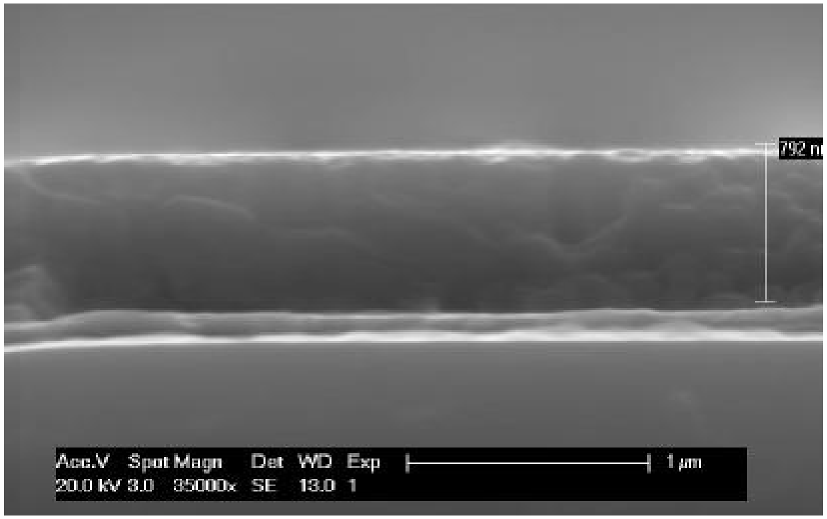
Dirk Kaden, Michael Kern
Fraunhofer Institut ISIT /
Oct. 2009

In situ growth of PZT

Process Result

- Target Composition $Pb_{1.22}(Zr_{0.52}Ti_{0.48})O_{1.22}$ / Growth Temperature 550°C
- The XRD shows almost 100% of (100) oriented perovskite Phase





Scott Harada, Paul Muralt, EPFL April 2010

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Thank you