
Industrial fabrication of piezoMEMS

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SINTEF

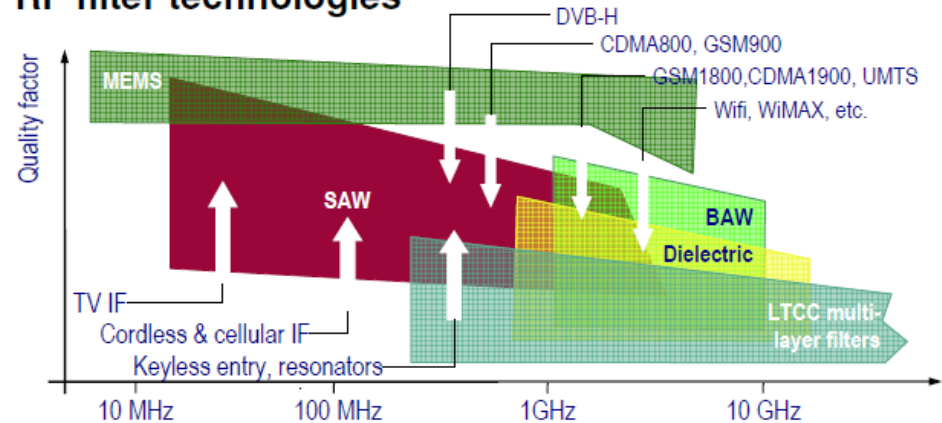
Outline

- ④ Outline
- ④ Background
 - ④ Current market situation
 - ④ Current situation regarding fabrication
- ④ What is needed for up-scaling of piezoMEMS fabrication
 - ④ Modeling
 - ④ Fabrication
 - ④ Tailored quality monitoring for piezoelectric thin films
- ④ Conclusions

Current market situation – AIN

- Several commercial actors use AIN for GHz filters
 - TDK-EPC (EPCOS)
- Filters main market for AIN but several other markets emerge. e.g.:
 - FBAR biosensors
 - Energy harvesting
- Production of AIN piezoMEMS is integrated into existing MEMS labs
 - Deposition by sputtering
 - AIN is CMOS compatible
 - Some MEMS foundries offer AIN

RF filter technologies



Current market situation – PZT

- Some large companies are working with PZT piezoMEMS
 - Ink-jet print heads
 - High f ultrasonic transducers (medical)
- Small and medium companies/ Universities have ideas where piezoelectric PZT technology is needed
 - Need access to PZT based piezoMEMS foundry
- Companies are looking for high volume production solutions for PZT
 - Prototyping
 - Deposition
 - Fabrication



Medical ultrasonic transducer by Vermon



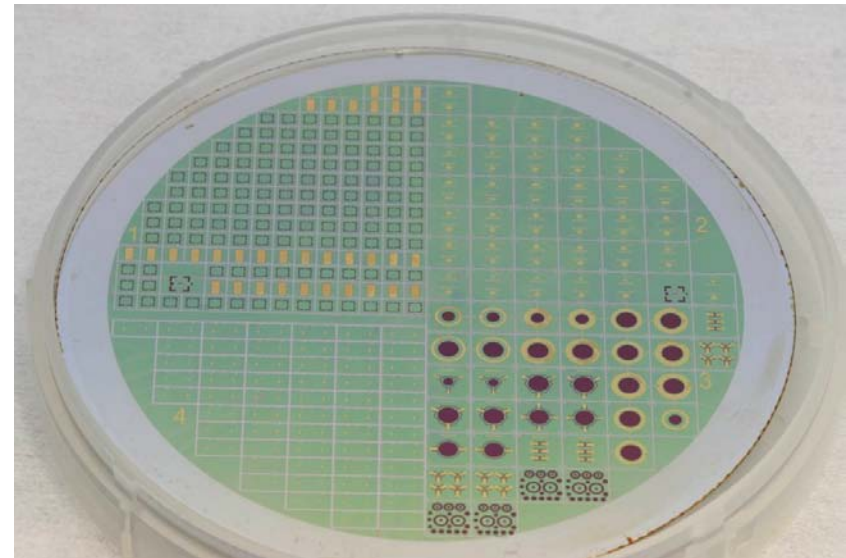
Ink-jet printer by Océ

How can my company access piezoMEMS production technology?

- Low volumes (prototyping)
- Production

Current situation regarding low volume prototyping

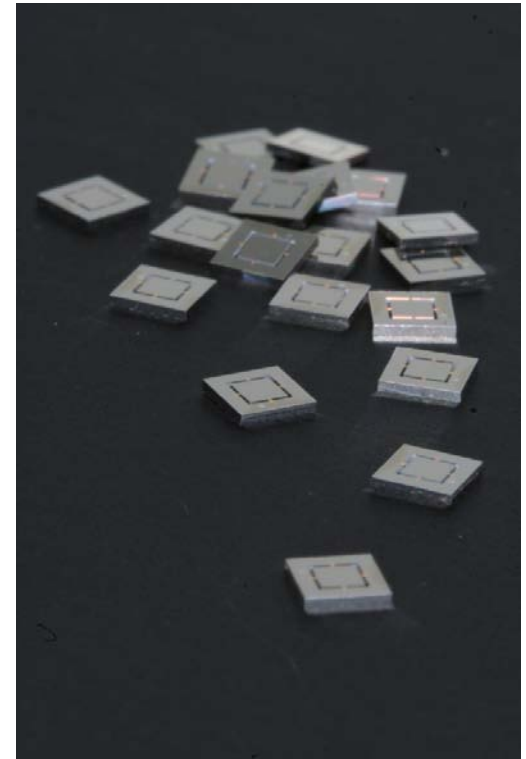
- In, Europe there are a few Universities/Institutes that offer piezoMEMS feasibility studies:
 - Cranfield University (UK), PZT
 - SINTEF (NO), PZT
 - EPFL (CH), AlN and PZT (research)
 - Fraunhofer ISIT, AlN (DE)
 - IMEC, AlN (BE)
- Only SINTEF has a predefined process with design guidelines and fabrication procedure (moveMEMS)



Multi-project piezoMEMS wafer from SINTEF

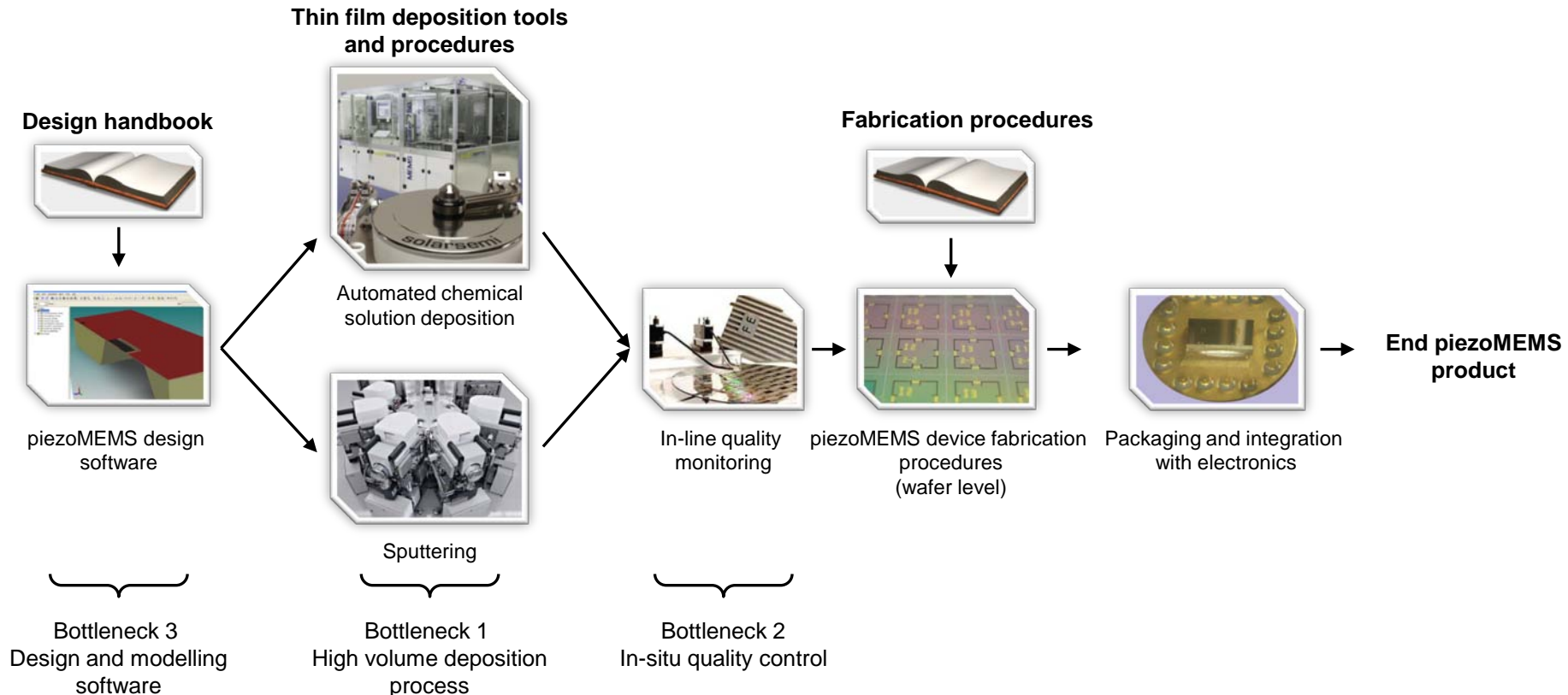
Current situation regarding high volume fabrication

- ④ There are 3 main bottlenecks for high volume fabrication
 - ④ High volume deposition
 - ④ AlN process already commercial (sputtering)
 - ④ Commercial PZT process being developed now (2010)
 - ④ Quality monitoring tool (piezoelectric coefficient)
 - ④ being developed in 2010
 - ④ piezoMEMS design and modelling tools (+procedures)
 - ④ being developed in 2010



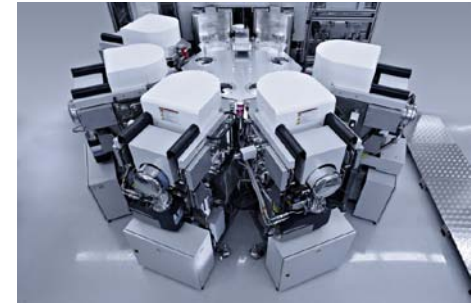
piezoMEMS accelerometers (SINTEF)

A piezoMEMS high volume fabrication process

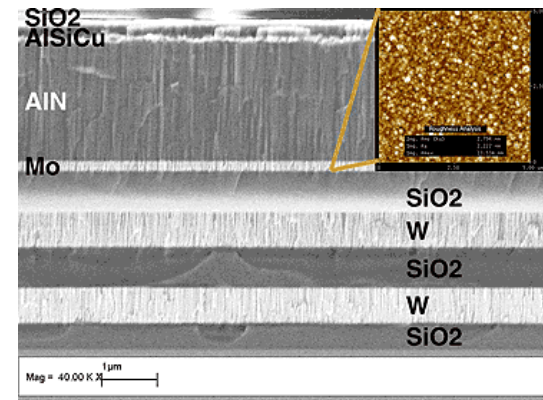


AlN piezoMEMS

- The deposition process for AlN has been commercial for several years.
 - Big companies have it in-house (FBAR filters)
- Not so much focus on AlN piezoMEMS for actuation (low $e_{31,f}$). Mostly sensing.
 - MFI (<http://www.memsfoundry.de>)
 - IMEC (www.imec.be)
 - EPFL (lc.epfl.ch) (research)
- Some use ZnO as well, but AlN has similar properties.

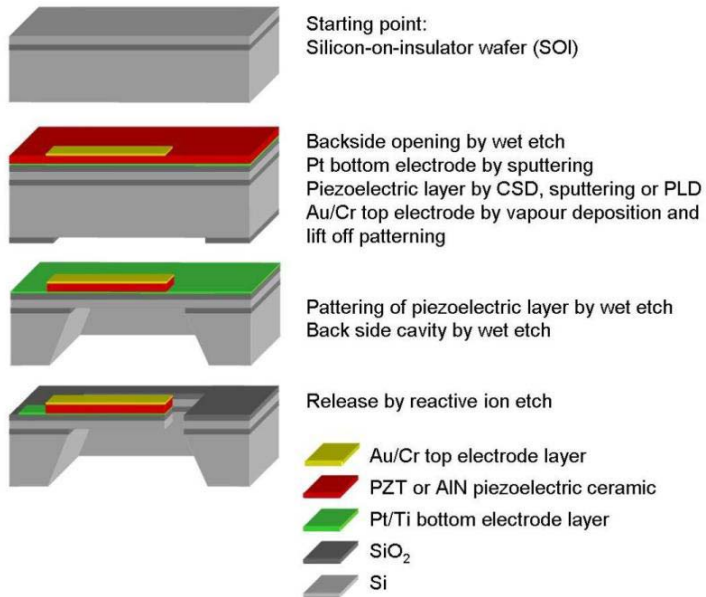


Oerlikon CLUSTERLINE 200 II



SEM cross-section image showing the SMR-type film stack

The *moveMEMS* process (PZT)



Release etch of piezoMEMS wafers

The *moveMEMS* design handbook

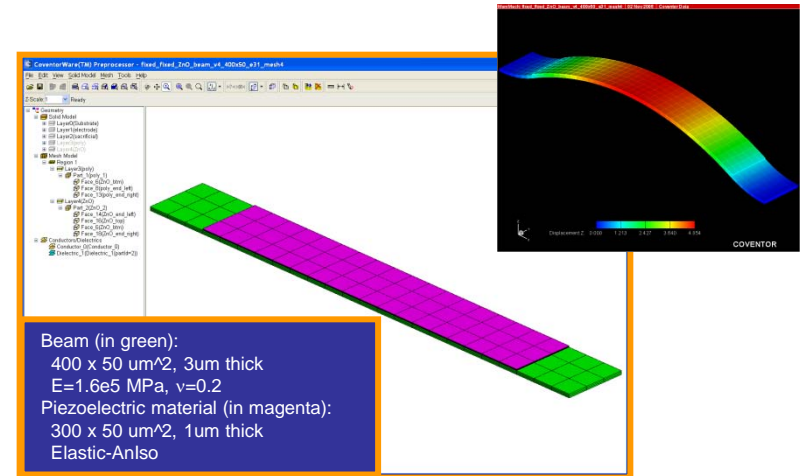
- ④ Material specifications and design guidelines
 - ④ Material parameters
 - ④ Design guidelines and process limitations
 - ④ Definition of lithographic masks

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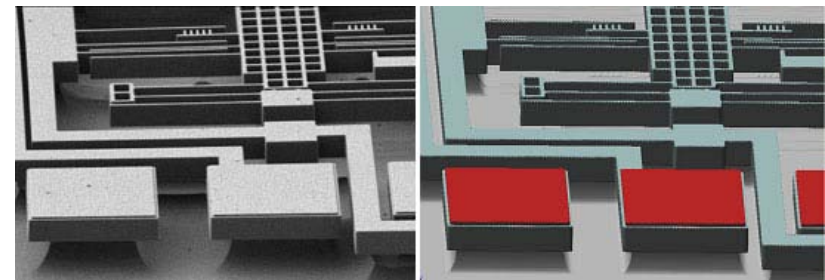
piezoMEMS modelling tool



- piezoMEMS modelling tool
 - 3D parametric library of standard piezoMEMS components
 - Integration with FEM software
 - Material parameters included in process design kit (PDK)
- Process emulation (virtual manufacturing)
 - 2D masks + description of fabrication process to create a voxel based 3D solid model.
- Virtual manufacturing
 - Save Money** by finding problems before fabrication.
 - Enhance communication** with highly detailed, interactive 3D models.
 - Reduce time-to-market** and gain a competitive advantage.
 - Improve documentation** and reduce document creation effort.
 - Enhance Yield** through improved design rules and defect modelling.



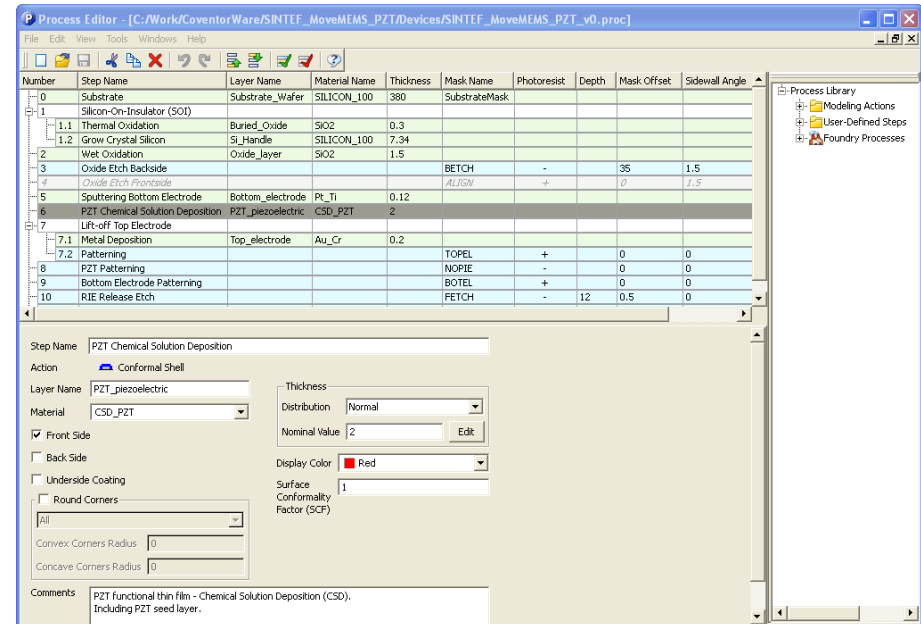
piezoMEMS beam in Coventorware ARCHITECT.



Virtual manufacturing of MEMS bond pads and comb drive.
Courtesy X-FAB Semiconductor Foundries, AG.

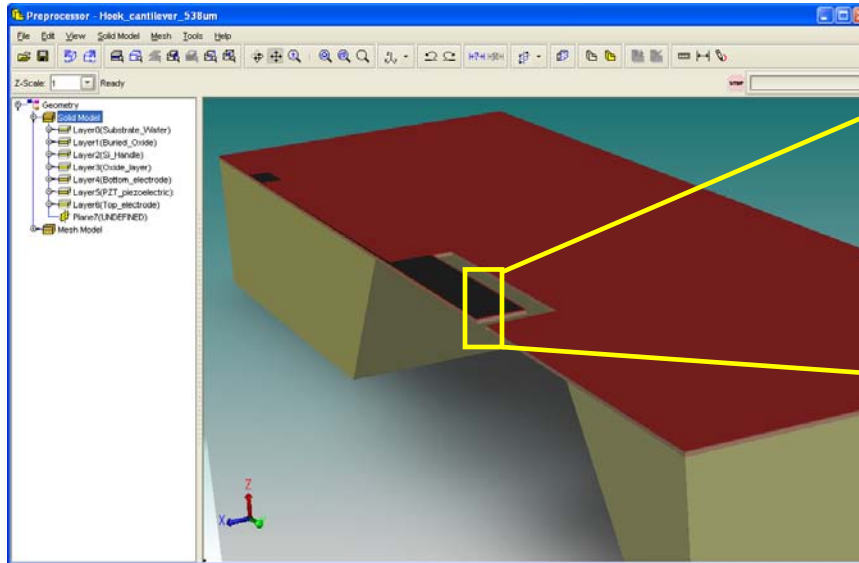
Process design kit (PDK)

- A Library of process emulation files (*.proc) define foundry-specific processes
- Material property database (*.mpd) provides process-specific values associated with materials
- Layout template file (*.cat, *.gds) contains geometric and process descriptions for pre-defined MEMS elements
- Library of parametric and non-parametric elements support schematic and physical design (optional)
- Link to design handbooks including validated MEMS design rules, detailed process information and design case studies are available upon request

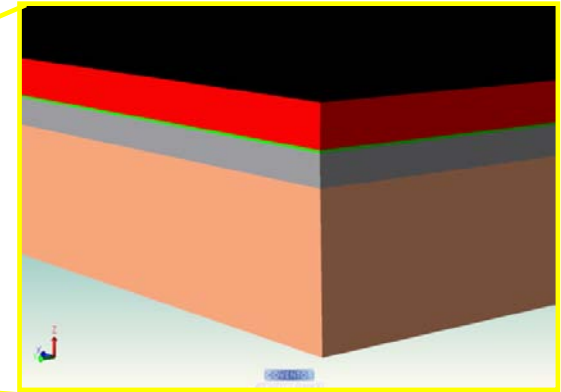


Process Flow of the piezoVolume PZT process represented in CoventorWare

Coventor architect and designer

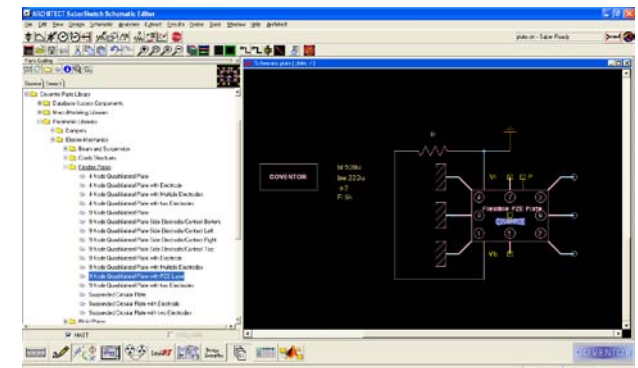


3D model of piezoelectric cantilever in *MoveMEMS PZT*



ZOOM: MoveMEMS PZT layers

- Piezoelectric actuators and sensors included (SINTEF moveMEMS) from version *2008.010*



PZT plate model for schematic design

Implementation in CoventorWare



The screenshot displays the CoventorWare Process Editor interface. The main window shows a process flow table with columns for Number, Step Name, Layer Name, Material Name, Thickness, Mask Name, Photoresist, and Depth. The 'Grow Crystal Silicon' step (1.2) is highlighted, showing a thickness of 7.34. Below the table, the detailed view for this step is shown, including the action 'Stack Material', layer name 'Si_Handle', material 'SILICON_100', and a thickness of 7.34. A 'Statistical Properties: Thickness' dialog box is open, showing tolerance and limit settings for the thickness.

Number	Step Name	Layer Name	Material Name	Thickness	Mask Name	Photoresist	Depth
0	Substrate	Substrate_Wafer	SILICON_100	380	SubstrateMask		
1	Silicon-On-Insulator (SOI)						
1.1	Thermal Oxidation	Buried_Oxide	SiO2	0.3			
1.2	Grow Crystal Silicon	Si_Handle	SILICON_100	7.34			
2	Wet Oxidation	Oxide_layer	SiO2	1.5			
3	Oxide Etch Backside				BETCH	-	
4	Oxide Etch Frontside				ALIGN	+	
5	Sputtering Bottom Electrode	Bottom_electrode	Pt_Ti	0.12			
6	PZT Chemical Solution Deposition	PZT_piezoelectric	CSD_PZT	2			
7	Lift-off Top Electrode						
7.1	Metal Deposition	Top_electrode	Au_Cr	0.2			
7.2	Patterning				TOPEL	+	
8	PZT Patterning				NOPIE	-	

Statistical Properties: Thickness

- Tolerance: 0
- Upper Limit: 7.84
- Lower Limit: 6.84

Buttons: Apply, Ok, Cancel

Implementation in CoventorWare



The image shows three overlapping dialog boxes in CoventorWare. The main dialog is 'Edit Materials in C:\Work\CoventorWare\SINTEF_MoveMEMS_PZT\Devices\SINTEF.mpd'. It contains a table of material properties for 'CSD_PZT'. Two red arrows originate from this table: one points to the 'Aniso' property, which is expanded into the 'Edit Aniso' dialog, and another points to the 'PiezoResistiveCoeffs(1/MPa)' property, which is expanded into the 'Edit PiezoElectric-Strain' dialog.

Property	Value
Material	CSD_PZT
Elastic Constants	Elastic-Iso
Density(kg/um ³)	Constant-Scalar
Stress(MPa)	Aniso
TCE Integral Form (1/K)	Constant-Scalar
ThermalCond(pW/umK)	Constant-Scalar
SpecificHeat(pJ/kgK)	Constant-Scalar
ElectricCond(pS/um)	Constant-Scalar
Dielectric	PiezoElectric-Strain
Viscosity(kg/um/s)	Constant-Scalar
PiezoResistiveCoeffs(1/MPa)	Constant_Scalar
Custom Properties File	Piezoelectric_constant_for_SINTEF_CSD_PZT

Edit Aniso dialog values:

- Sx: 8.500000e+001
- Sy: 8.500000e+001
- Sz: 0.000000e+000

Edit PiezoElectric-Strain dialog values:

D1	0.000000e+000	0.000000e+000	-1.360000e-004
D2	0.000000e+000	0.000000e+000	-1.360000e-004
D3	0.000000e+000	0.000000e+000	2.720000e-004
D4	0.000000e+000	0.000000e+000	0.000000e+000
D5	5.000000e-004	0.000000e+000	0.000000e+000
D6	0.000000e+000	5.000000e-004	0.000000e+000
Dielectric	1.300000e+003	1.300000e+003	1.200000e+003

Choice of PZT deposition method

	$-e_{31,f}$ [C/m ²]	Relative permittivity. ϵ_r	Dissipation factor, tan d	Current main bottleneck for high volume
CSD	12-18	1100-1600	~0.03	Throughput
Sputtering	~4-8?	900?		Quality

- ⦿ CSD: High quality, but low throughput (manual deposition ~1 wafer/h μm)
- ⦿ Sputtering:
 - ⦿ Multi target DC reactive sputtering: low throughput
 - ⦿ Single oxide target RF sputtering: higher throughput, but still too low quality
- ⦿ PLD also coming up as candidate

Production deposition tools for PZT – CSD

- Adaptation of Solar-semi cluster coater tool
- Throughput goal
 - 4 wafers/h- μm (65 nm/min) on 200 mm wafers using new automatic CSD tool (15.000 wafers/y @ 43 % uptime)
- Performance goal
 - $e_{31,f} \sim -14 \text{ C/m}^2$
- Deposition cost
 - 10-20 €/wafer- μm due to consumables and equipment depreciation @ 43 % uptime
 - 4-8 €cent per 1x1 cm die using 200 mm wafers
- Will be optimized for PZT but can also be used for other oxides



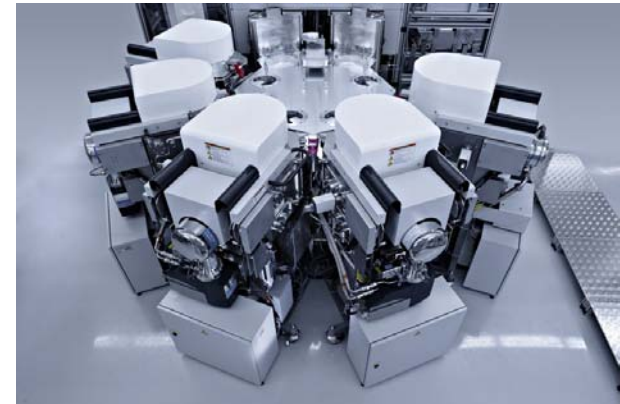
Solar-semi coating cluster



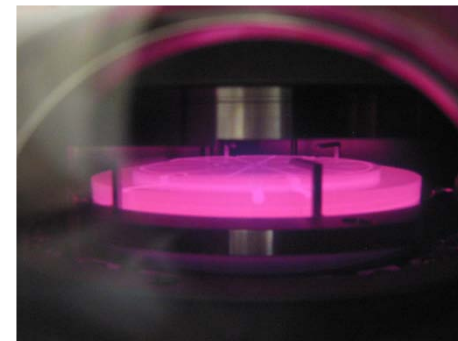
Production deposition tools for PZT – sputtering



- Development of add-on for Oerlikon's Clusterline 200 II for in-situ sputtering of PZT
- Throughput goal
 - 3.6 wafers/h- μm (60 nm/min) on 200 mm wafers (11.000 wafers/y @ 43 % uptime)
- Performance goal
 - $e_{31,f} \sim -14 \text{ C/m}^2$
- Deposition cost
 - 10-20 €/wafer- μm due to consumables and equipment depreciation @ 43 % uptime
 - 4-8 €cent per 1x1 cm die using 200 mm wafers



Oerlikon Systems Clusterline 200 II



Hot chuck during sputtering



How to do quality monitoring?

Method	Information retrieved	Suitability for high volume piezo thin film quality monitoring
In-situ XRD	Structure/texture/morphology	No 1:1 correlation between e.g. rocking curve and piezoelectric performance
Ellipsometry	Thickness/refractive index	Only thickness
Electromechanical	Piezoelectric coefficients/ ϵ_r	Wafer must be processed to extract the coefficients

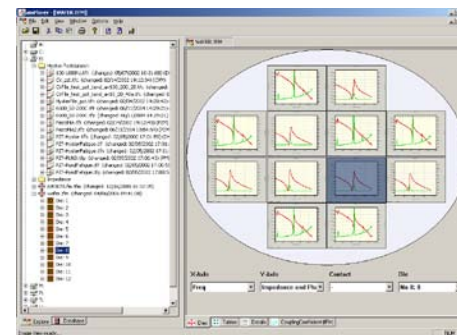
In-line quality monitoring

- Indirect estimation of $e_{31,f}$ from $d_{33,f}$ and ε
 - Needed resolution for thin films <10 pm
 - Laser interferometry
- Accuracy
 - Better 4 % of real $e_{31,f}$
- Throughput
 - 10 wafers/h
- Automation of measurements through electrode mask layout
 - Parameter/coefficient tracking
- Operations cost
 - 4 €/wafer due to equipment depreciation @ 43 % uptime

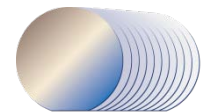


aixACT
SYSTEMS GMBH

aixACCT double beam laser interferometer (aixDBLI)



aixPlover data management and analysis software



piezoVolume

piezoMEMS competence centre

- 🌀 The competence centre aims to act as contact point for interested parties and covers the whole production process for piezoelectric microsystems



- 🌀 World-class piezoelectric thin films (PZT). $e_{31,f} \sim -14 \text{ C/m}^2 @ 10 \text{ Hz}$
- 🌀 Deposition process and tools for high-performance PZT thin films on silicon wafers
- 🌀 Modelling software specifically for piezoMEMS
- 🌀 Modelling of device ideas and design assistance
- 🌀 Evaluation of alternative processing routes
- 🌀 Testing services and sophisticated testing equipment
- 🌀 Manufacturing of prototypes
- 🌀 Small scale production using 150 mm wafers

- 🌀 www.piezovolume.com



Conclusions

- ④ There is a high focus on establishing production technologies for piezoMEMS (PZT)
- ④ Low volume prototyping
 - ④ AIN are offered by some MEMS foundries
 - ④ PZT are offered by some commercially by a few institutes
- ④ High volume fabrication
 - ④ AIN already at high volumes in companies
 - ④ PZT deposition processes currently under development
 - ④ High volume deposition tools
 - ④ Chemical solution deposition (piezoVolume)
 - ④ Sputtering (piezoVolume)
 - ④ PLD (SolMates)
 - ④ Process specific design and modelling tool
 - ④ Quality monitoring tool