Industrial fabrication of piezoMEMS

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SINTEF

Piezo INSTITUTE
The European Institute for Piezoelectric Materials and Devices

Outline

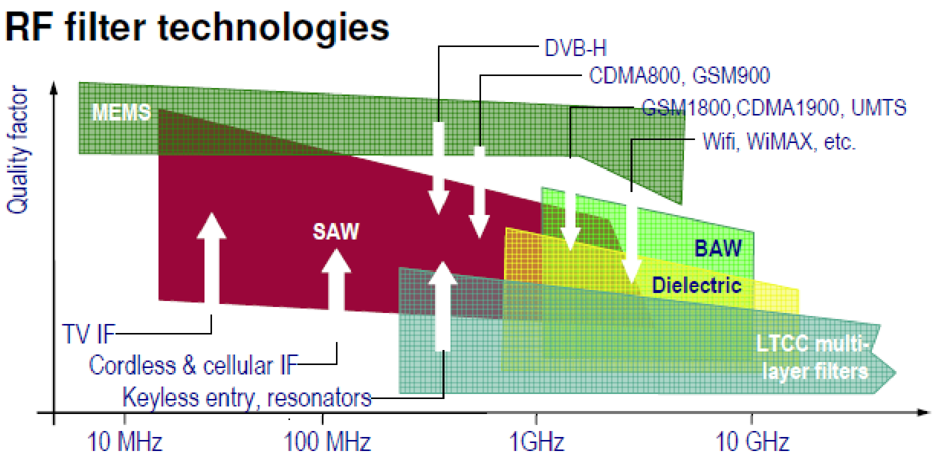
- Outline
- Background
  - Current market situation
  - Current situation regarding fabrication
- What is needed for up-scaling of piezoMEMS fabrication
  - Modeling
  - Fabrication
  - Tailored quality monitoring for piezoelectric thin films
- Conclusions

Current market situation – AlN

- Several commercial actors use AlN for GHz filters
  - TDK-EPC (EPCOS)

  - Filters main market for AlN but several other markets emerge. e.g.:
    - FBAR biosensors
    - Energy harvesting

- Production of AlN piezoMEMS is integrated into existing MEMS labs
  - Deposition by sputtering
  - AlN is CMOS compatible
  - Some MEMS foundries offer AlN



Current market situation – PZT

- Some large companies are working with PZT piezoMEMS
  - Ink-jet print heads
  - High f ultrasonic transducers (medical)

Medical ultrasonic transducer by Vermon

- Small and medium companies/ Universities have ideas where piezoelectric PZT technology is needed
  - Need access to PZT based piezoMEMS foundry

Ink-jet printer by Océ

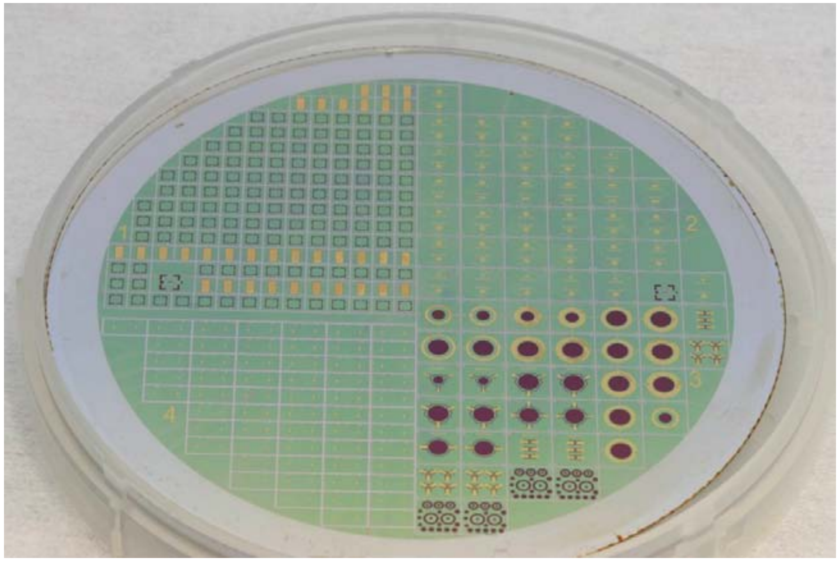
- Companies are looking for high volume production solutions for PZT
  - Prototyping
  - Deposition
  - Fabrication

How can my company access piezoMEMS production technology?

- Low volumes (prototyping)
- Production

Current situation regarding low volume prototyping

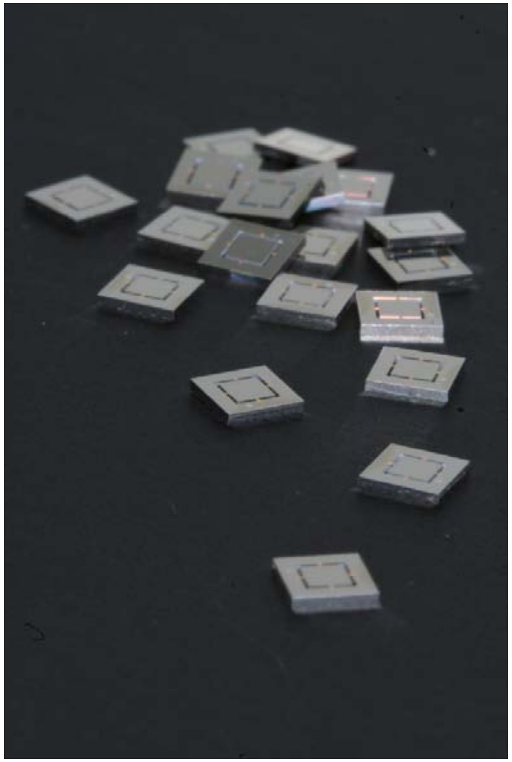
- In, Europe there are a few Universities/Institutes that offer piezoMEMS feasibility studies:
    - Cranfield University (UK), PZT
    - SINTEF (NO), PZT
    - EPFL (CH), AlN and PZT (research)
    - Fraunhofer ISIT, AlN (DE)
    - IMEC, AlN (BE)
- Only SINTEF has a predefined process with design guidelines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



Multi-project piezoMEMS wafer from SINTEF

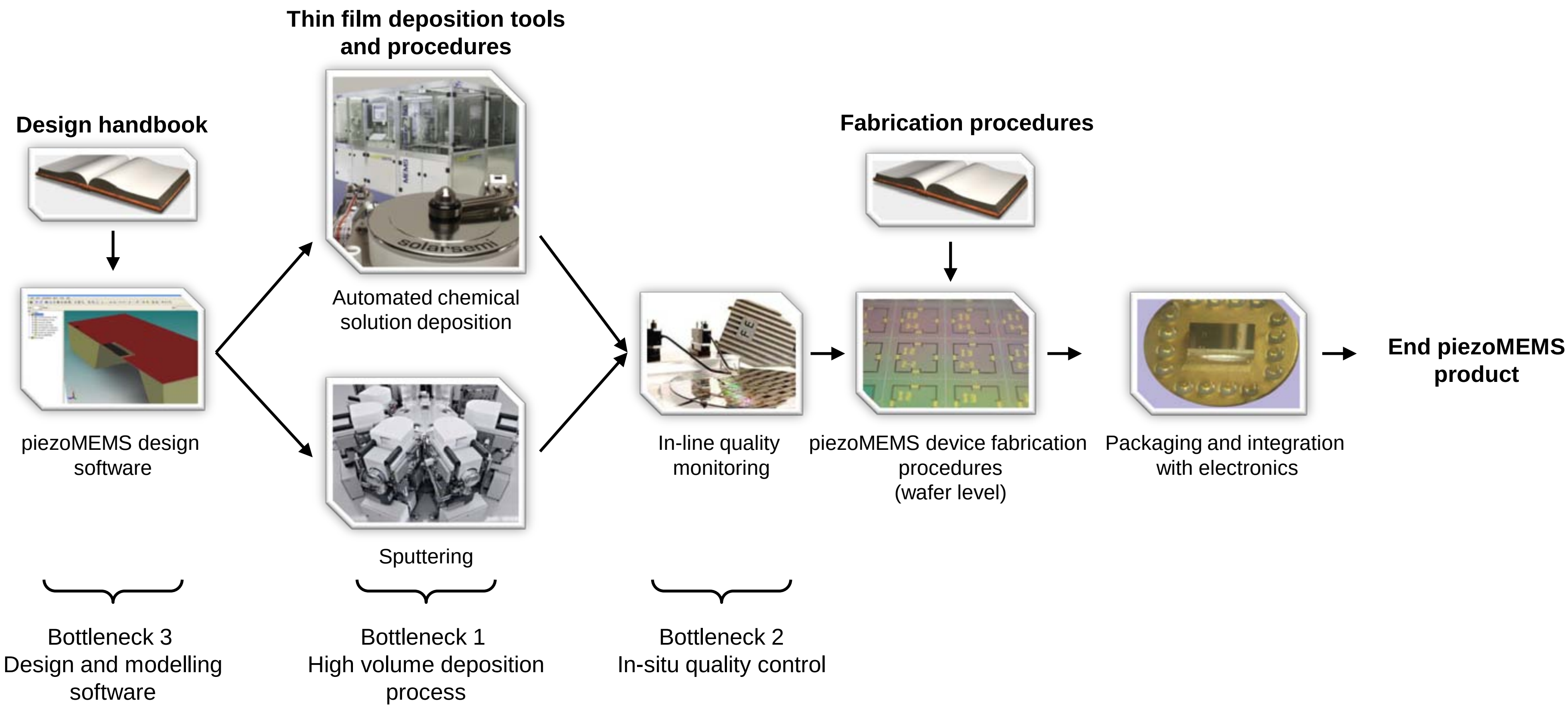
Current situation regarding high volume fabrication

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



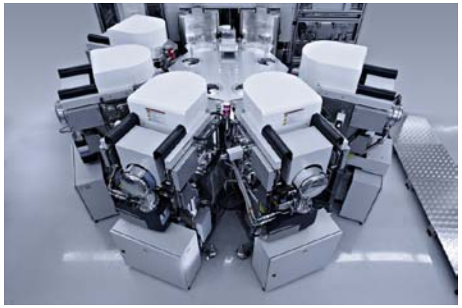
piezoMEMS accelerometers (SINTEF)

A piezoMEMS high volume fabrication process

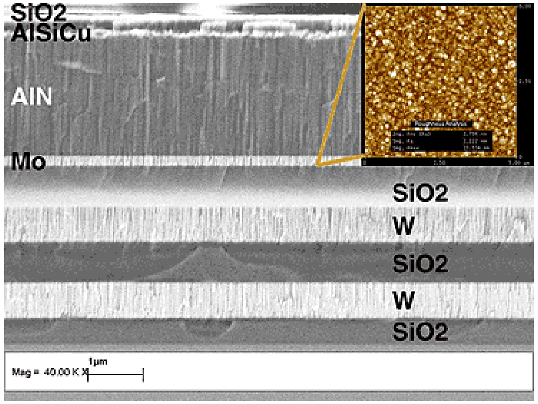


AlN piezoMEMS

- 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)

piezoVolume

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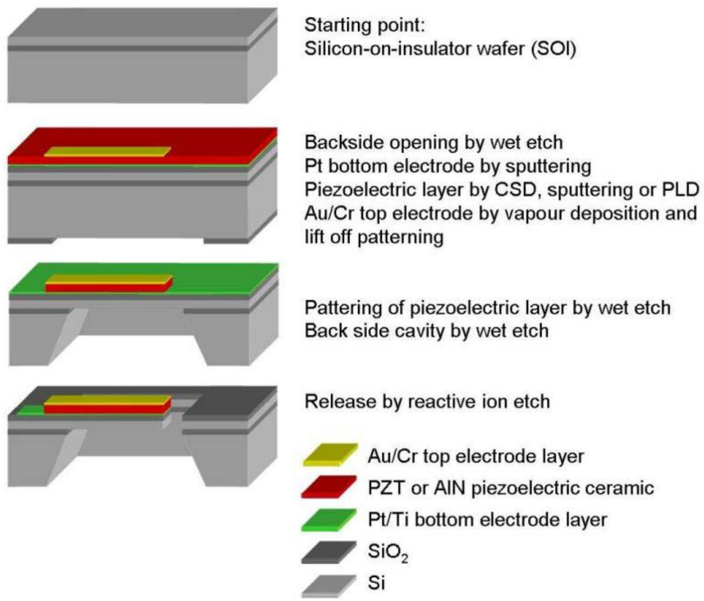

Release etch of piezoMEMS wafers

The *moveMEMS* design handbook

SINTEF

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

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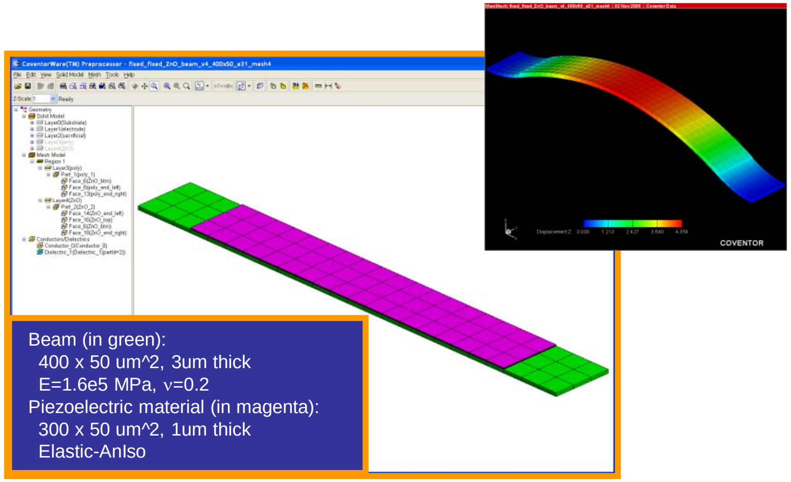
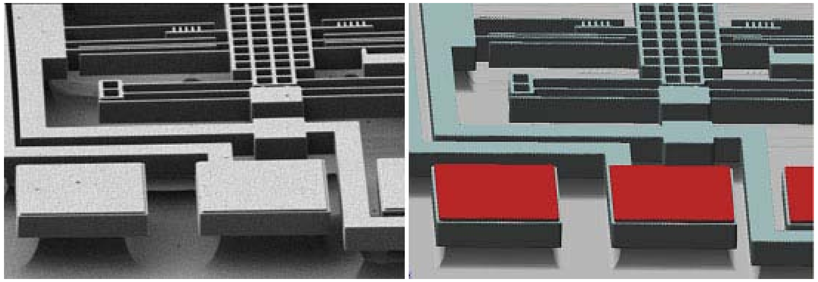
piezoMEMS modelling tool

- 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.



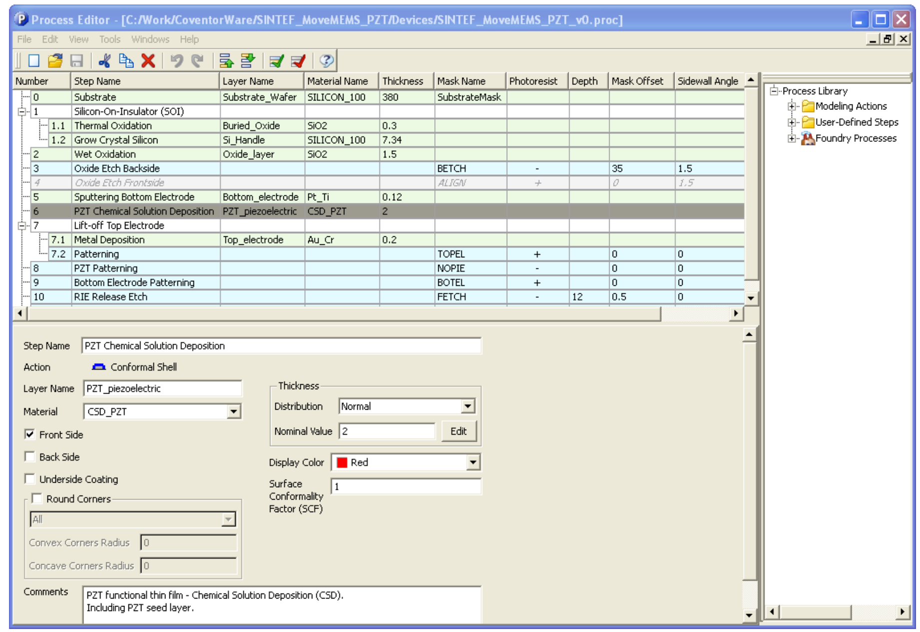
piezoMEMS beam in Coventorware ARCHITECT.



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

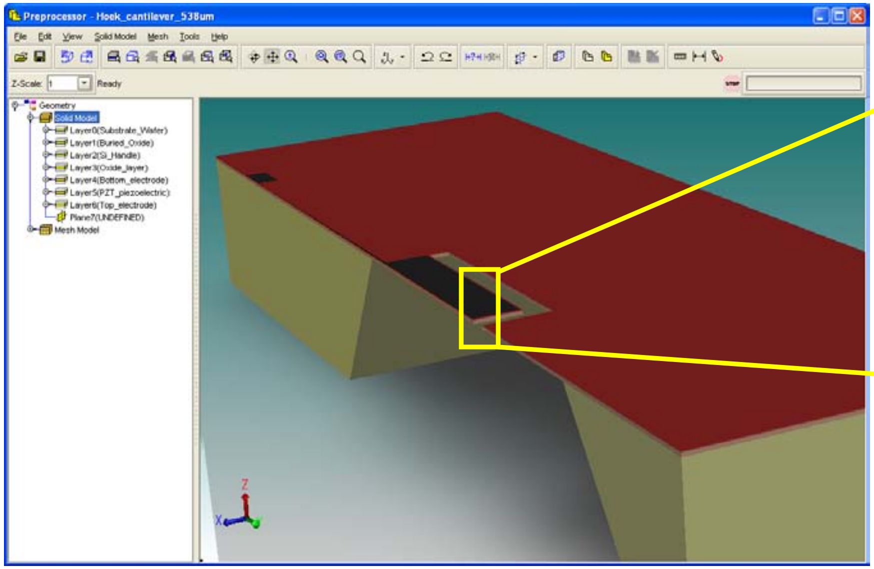
Process design kit (PDK)

- 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

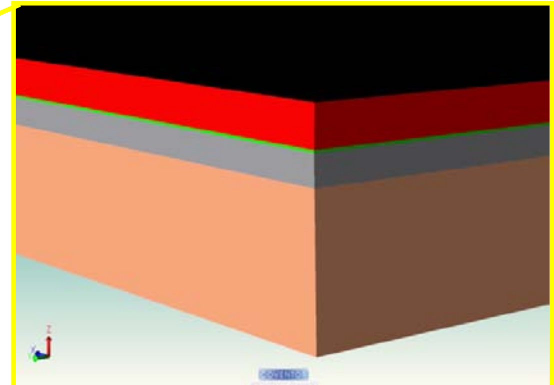


Process Flow of the piezoVolume PZT process represented in CoventorWare

Coventor architect and designer

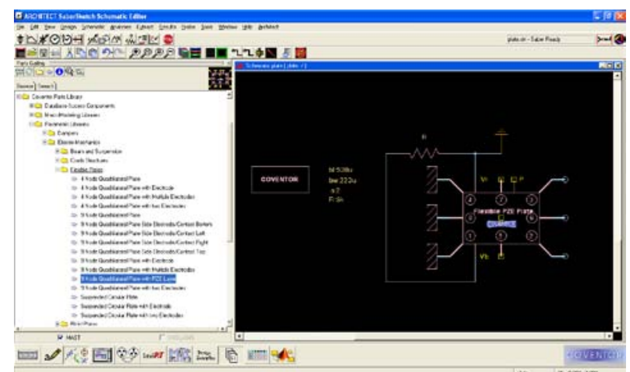


3D model of piezoelectric cantilever in *MoveMEMS PZT*



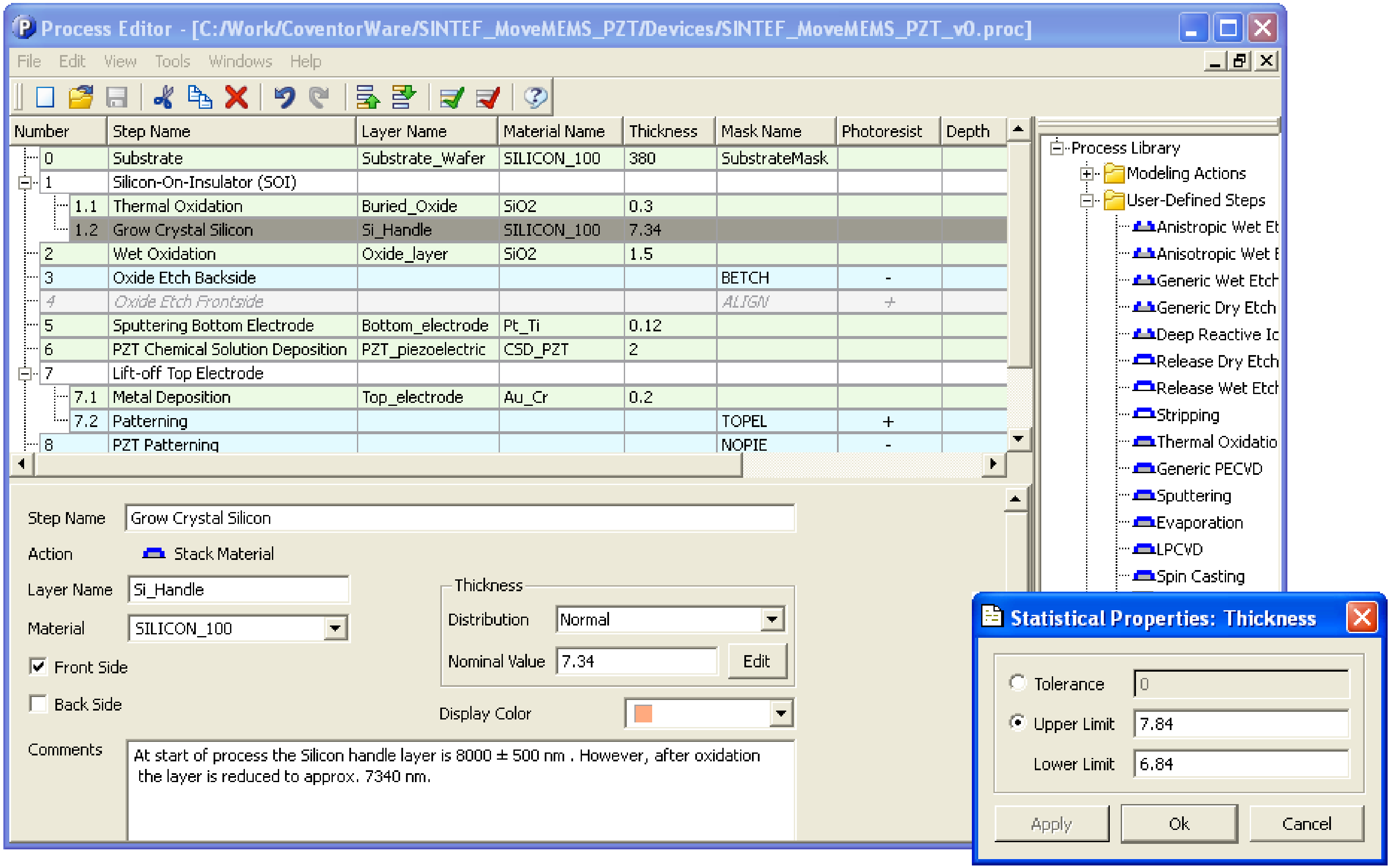
ZOOM: MoveMEMS PZT layers

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

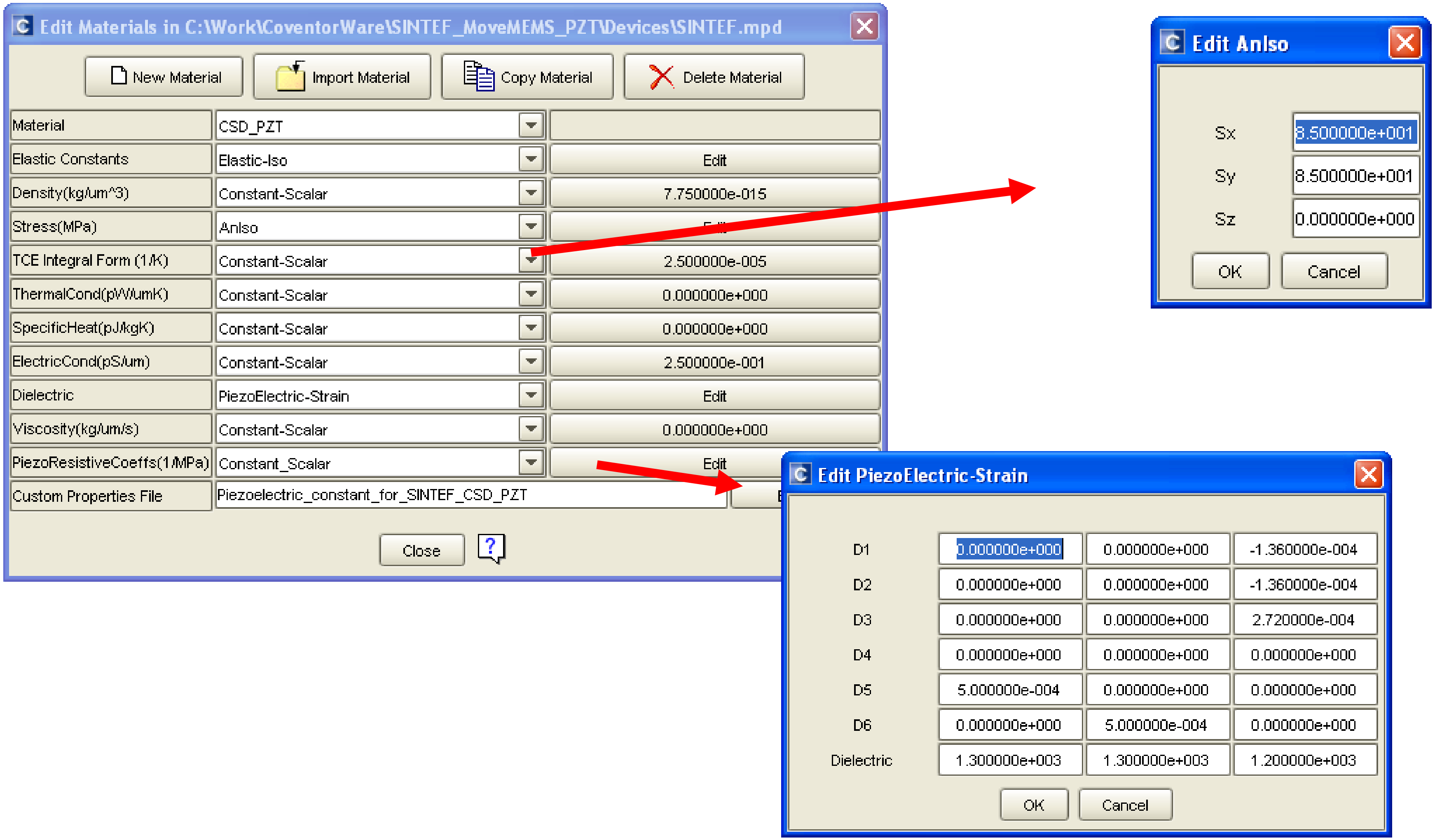


PZT plate model for schematic design

Implementation in CoventorWare



Implementation in CoventorWare



Choice of PZT deposition method

	$-e_{31,f}$ [C/m^2]	Relative permittivity. e_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

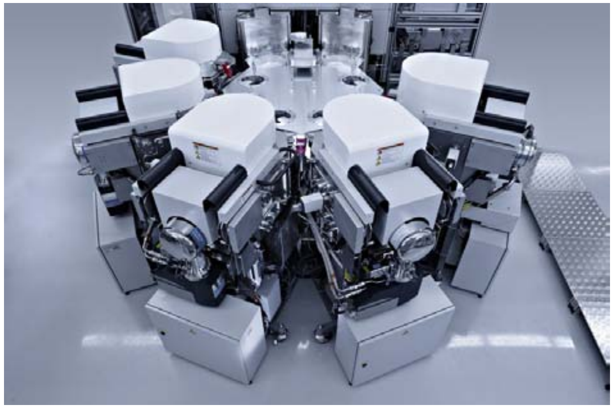
- Adaptation of Solar-semi cluster coater tool
- Throughput goal
  - 4 wafers/h·µm (65 nm/min) on 200 mm wafers using new automatic CSD tool (15.000 wafers/y @ 43 % uptime)
- Performance goal
  - $e_{31,f} \sim -14\ C/m^2$
- Deposition cost
  - 10-20 €/wafer·µm due to consumables and equipment depreciation @ 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

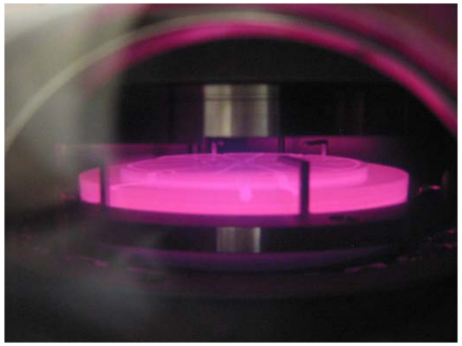
43 % uptime = 12h/day and 6d/week

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
  - $e_{31,f}$ ~ -14 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

43 % uptime = 12h/day and 6d/week

How to do quality monitoring?

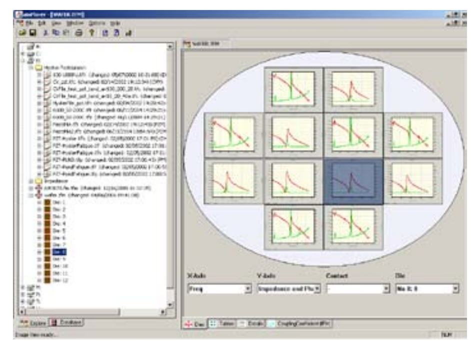
Method	Information retrieved	Suitability for high volume piezo thin film quality monitoring
In-situ XRD	Structure/texture/ morphology	No 1:1 correlation between e.g. rocking curve and piezoelectric performance
Ellipsometry	Thickness/refractive index	Only thickness
Electromechanical	Piezoelectric coefficients/ε_r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



aixPlorer data management and analysis software

piezoVolume

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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). $e_{31,f}$ ~ -14 C/m^2 @ 10 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

piezoVolume

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Conclusions

- There is a high focus on establishing production technologies for piezoMEMS (PZT)

- Low volume prototyping
  - AlN are offered by some MEMS foundries
  - PZT are offered by some commercially by a few institutes

- High volume fabrication
  - AlN already at high volumes in companies

  - PZT deposition processes currently under development
    - High volume deposition tools
      - Chemical solution deposition (piezoVolume)
      - Sputtering (piezoVolume)
      - PLD (SolMates)

  - Process specific design and modelling tool

  - Quality monitoring tool