COMSOL CONFERENCE 2011

Multiphysics Modeling and Simulation

Design and Characterization of a Novel High-g Accelerometer

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EMI

OUTLINE

- Introduction: Novel High-g Accelerometer
  - Accelerometer design and functional principle

- Extension of COMSOL material model

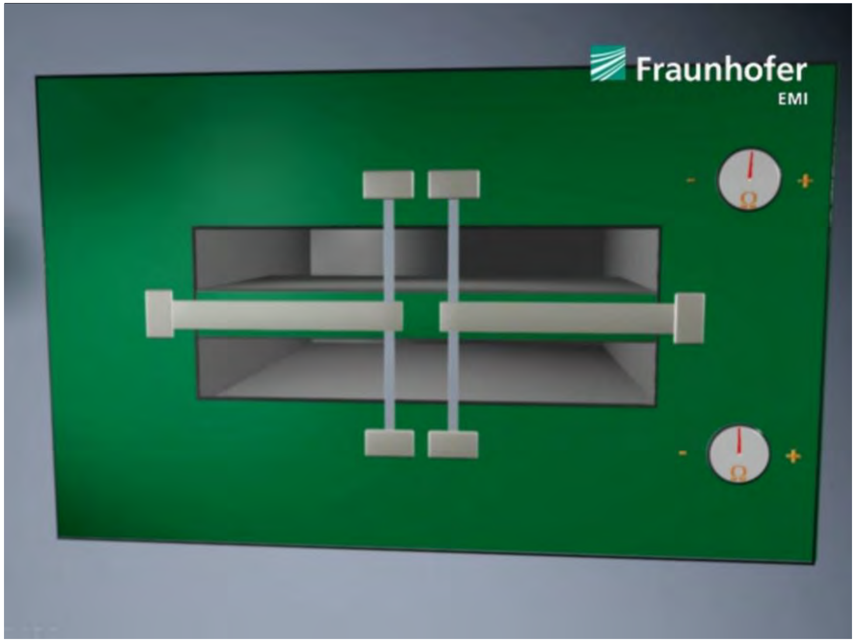
- Wafer-level characterization
  - Electro-mechanical characterization
  - Thermal characterization

- Summery and outlook

EMI Accelerometer

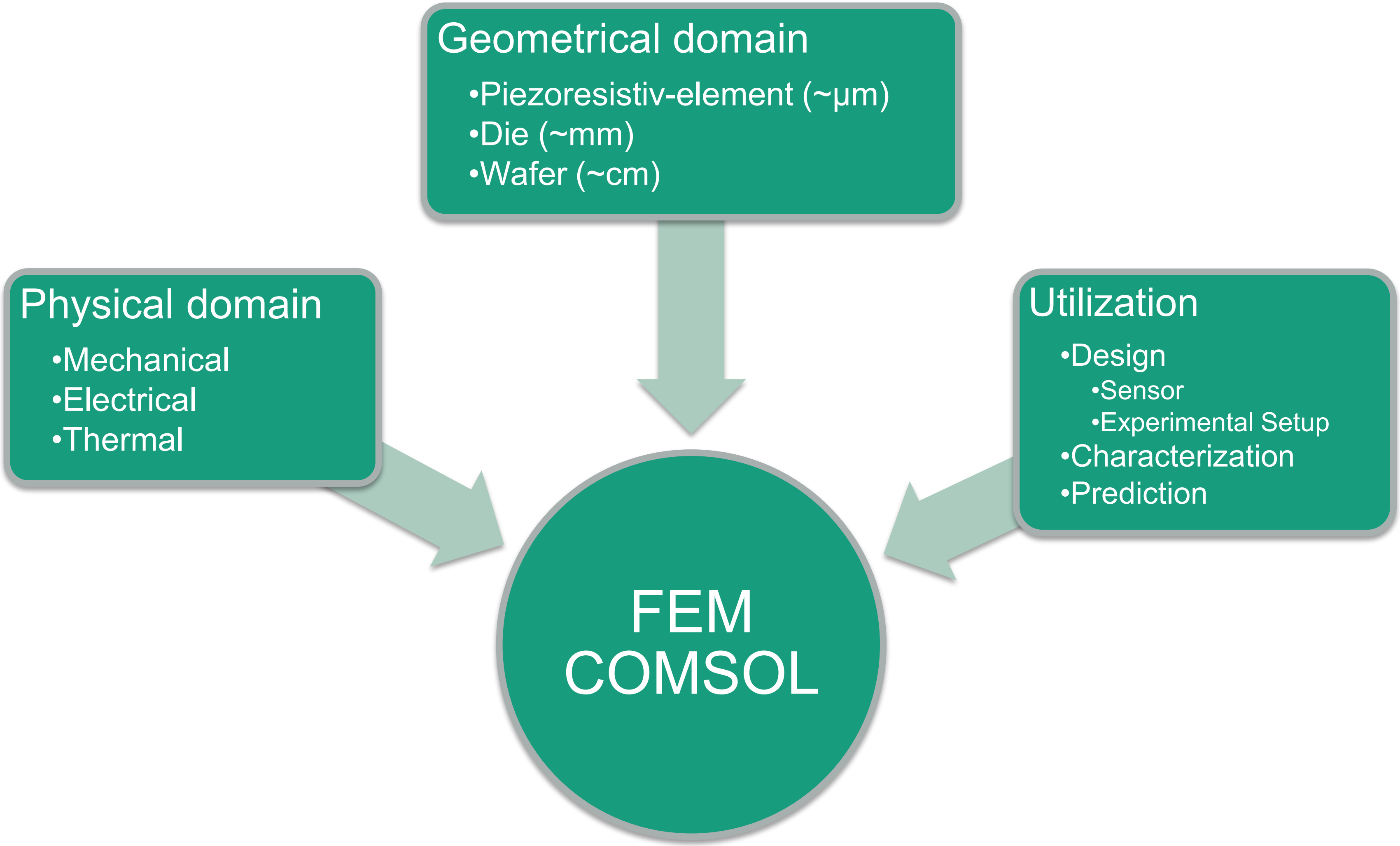
Design and Functional Principle

- Main components:
  - Flexural plate (spring-mass system)
  - Self-supporting piezoresistive (PR) elements
  - Rigid frame
- Functional principle:
  - Inertial forces cause deflection of plate
  - Straining of piezoresistive elements
  - Change in resistance is measurement signal



single crystal silicon MEMS

Use of COMSOL for Accelerometer Development



Geometrical domain

- Piezoresistiv-element (~µm)
- Die (~mm)
- Wafer (~cm)

Physical domain

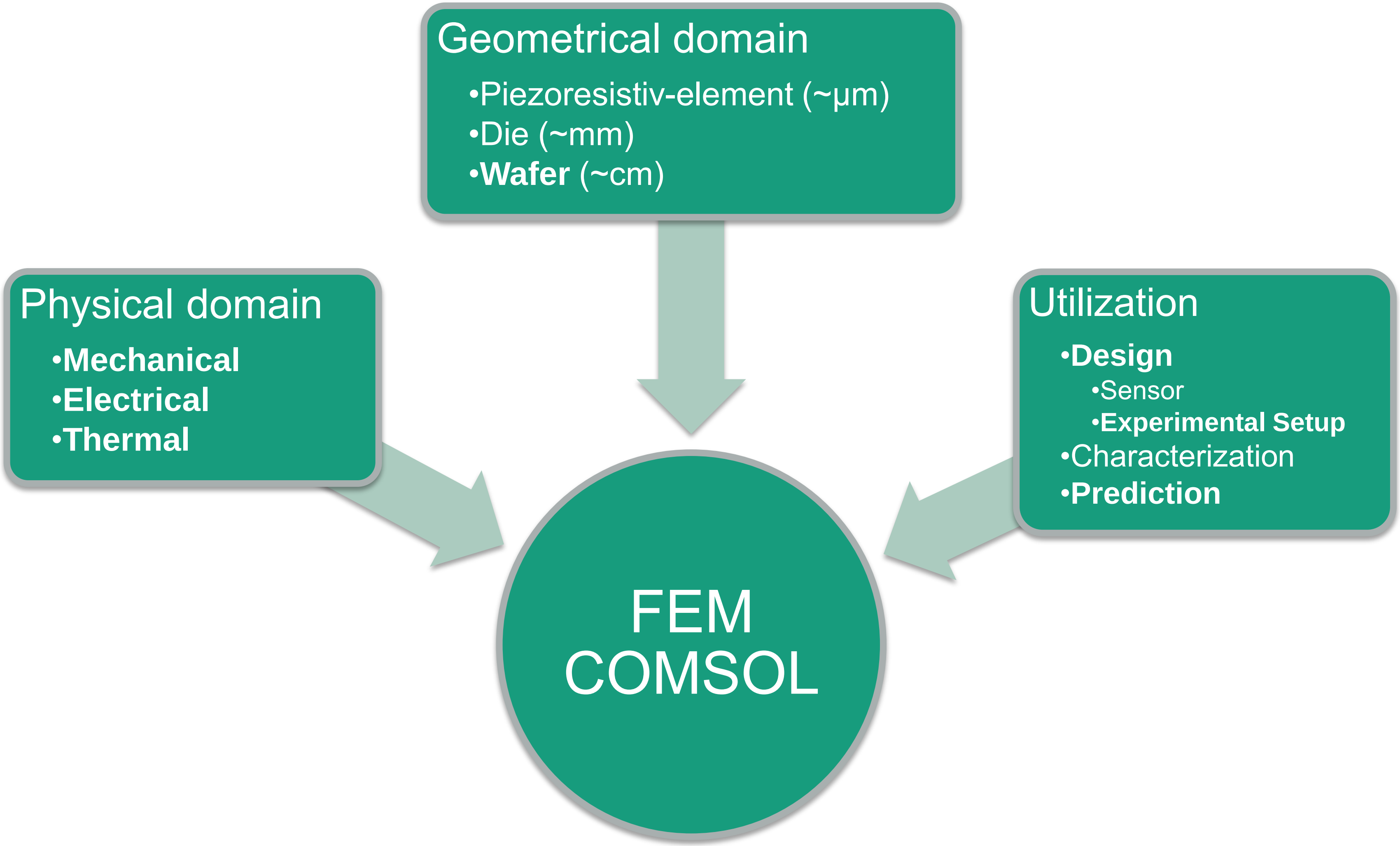
- Mechanical
- Electrical
- Thermal

Utilization

- Design
  - Sensor
  - Experimental Setup
- Characterization
- Prediction

FEM
COMSOL

Use of COMSOL for Accelerometer Development



Geometrical domain

- Piezoresistiv-element (~µm)
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- **Wafer** (~cm)

Physical domain

- **Mechanical**
- **Electrical**
- **Thermal**

Utilization

- **Design**
  - Sensor
  - **Experimental Setup**
- Characterization
- **Prediction**

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Extension of the COMSOL Material Model

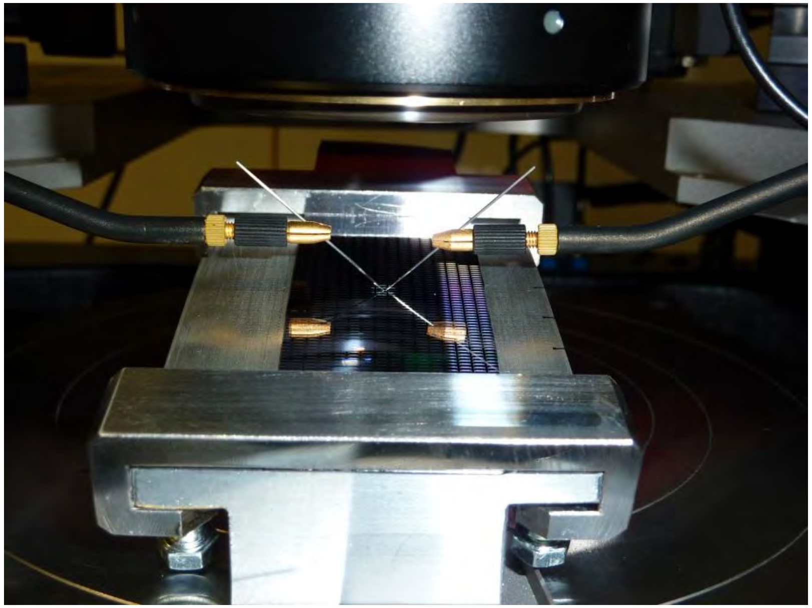
For Single Crystal Silicon

- Material: single crystal silicon
- Implemented properties in COMSOL:
  - Anisotropy
  - Basic mechanical-, electrical-, thermal-behaviors
  - Coupling of the physical domains (e.g. thermal expansion)
- Needed description of:
  - Temperature dependence of thermal expansion
  - Temperature depended PR-effect
  - Doping dependence of the PR-effect

} implemented
in this work

Wafer-Level Characterization

- Wafer-level Characterization of the PR-elements on
  - Static straining of the elements
  - … and heating of the elements
- Advantages:
  - Easy handling of many sensors
  - Large number of measurements in a short time

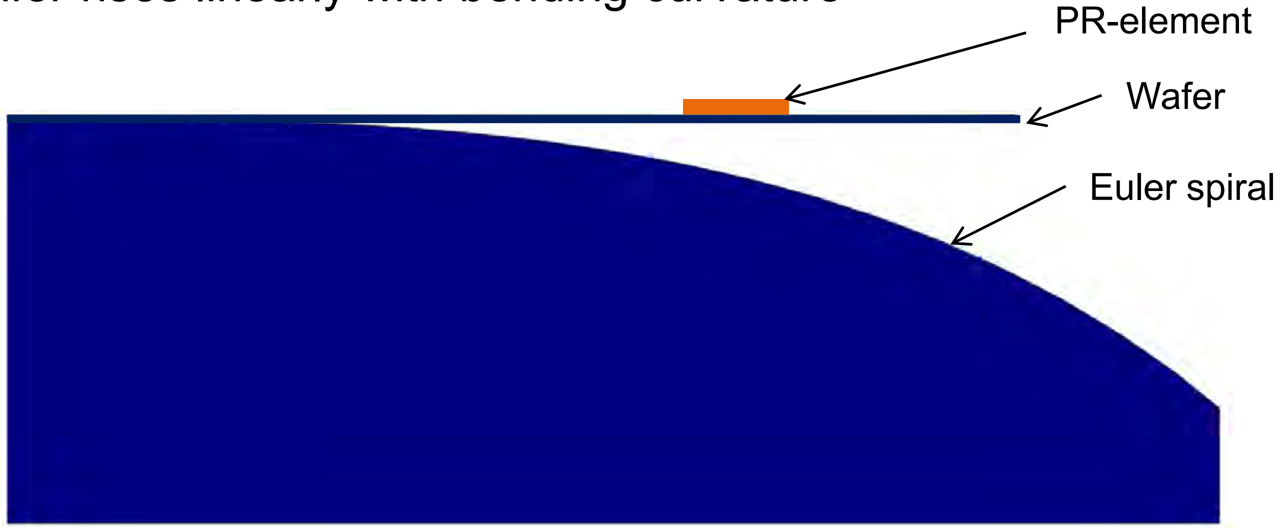


Electro-Mechanical Characterization

Generation of Linearly Rising Stress

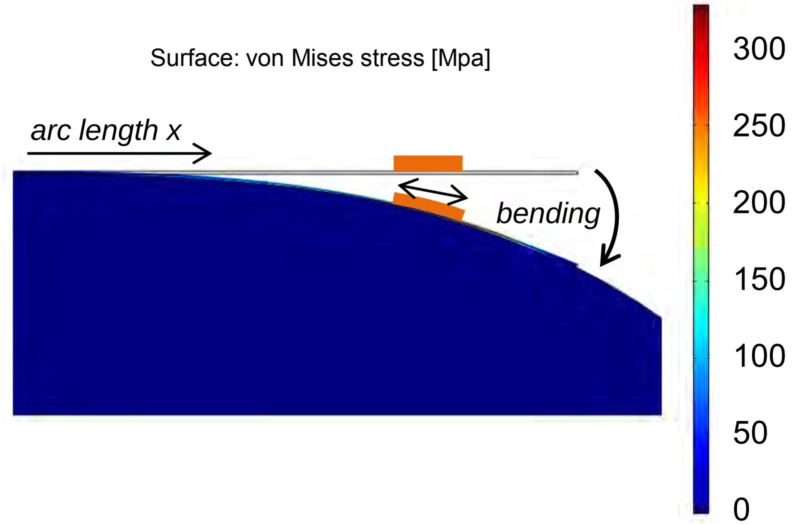
- Characterization of PR-elements on wafer-level

- Idea:
  - Generate mech. stress by bending
  - Stress in bent wafer rises linearly with bending curvature

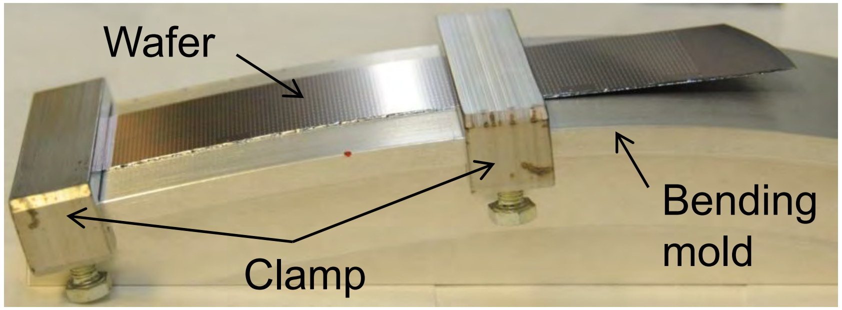


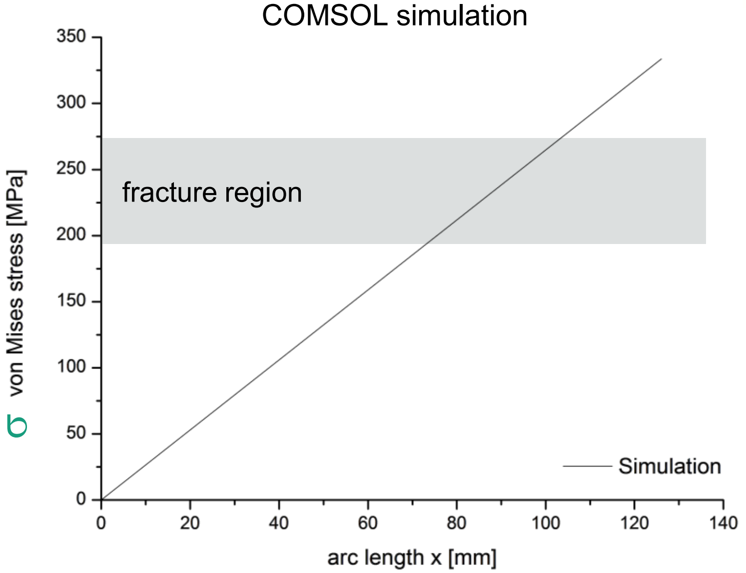
Electro-Mechanical Characterization

Generation of Linearly Rising Stress



- Design of bending mold based on COMSOL simulation
- Setup only possible with wafer-level characterization
- Simple measurement with prober





Electro-Mechanical Characterization

On-Chip Characterization of the PR-Elements

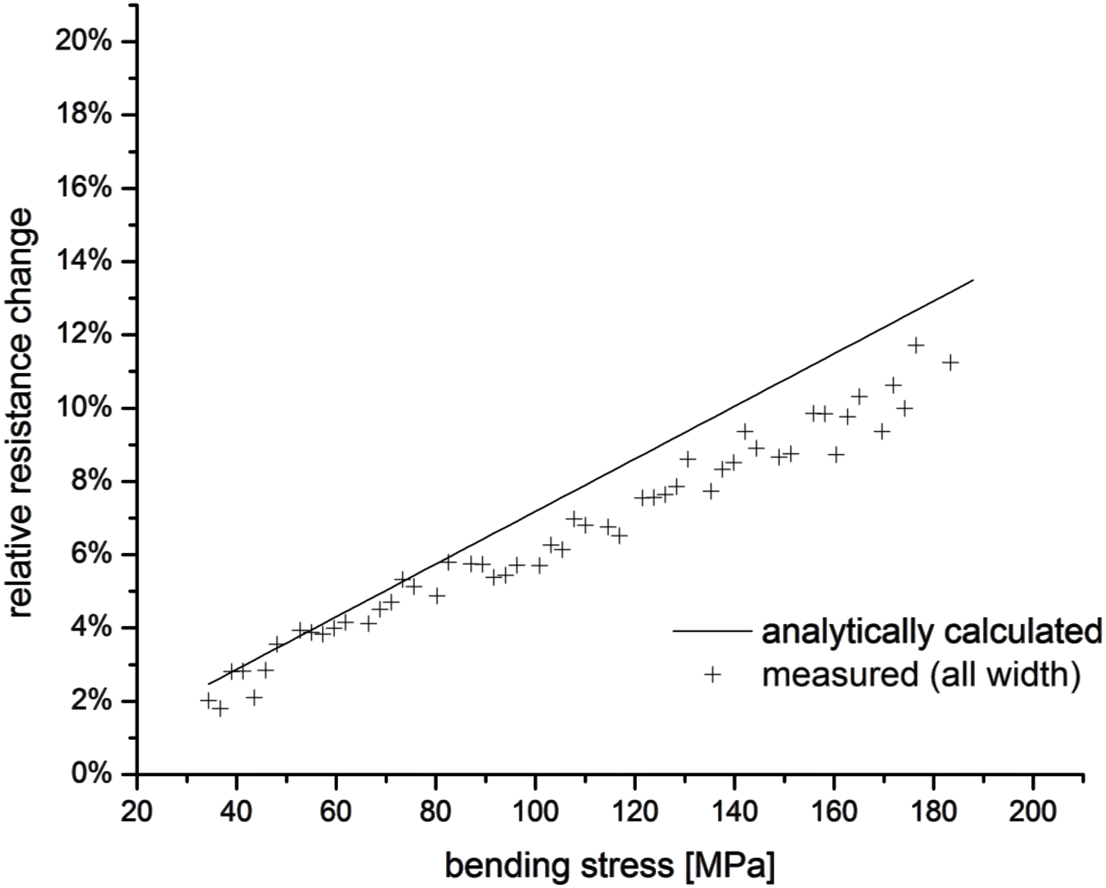
- Analytic calculation:

$$\frac{\Delta R}{R} \approx \sigma_l \cdot \pi_l$$

(neglecting transverse tensions)

σ_l : mech. stress → from COMSOL
π_l: PR-coefficient → from literature

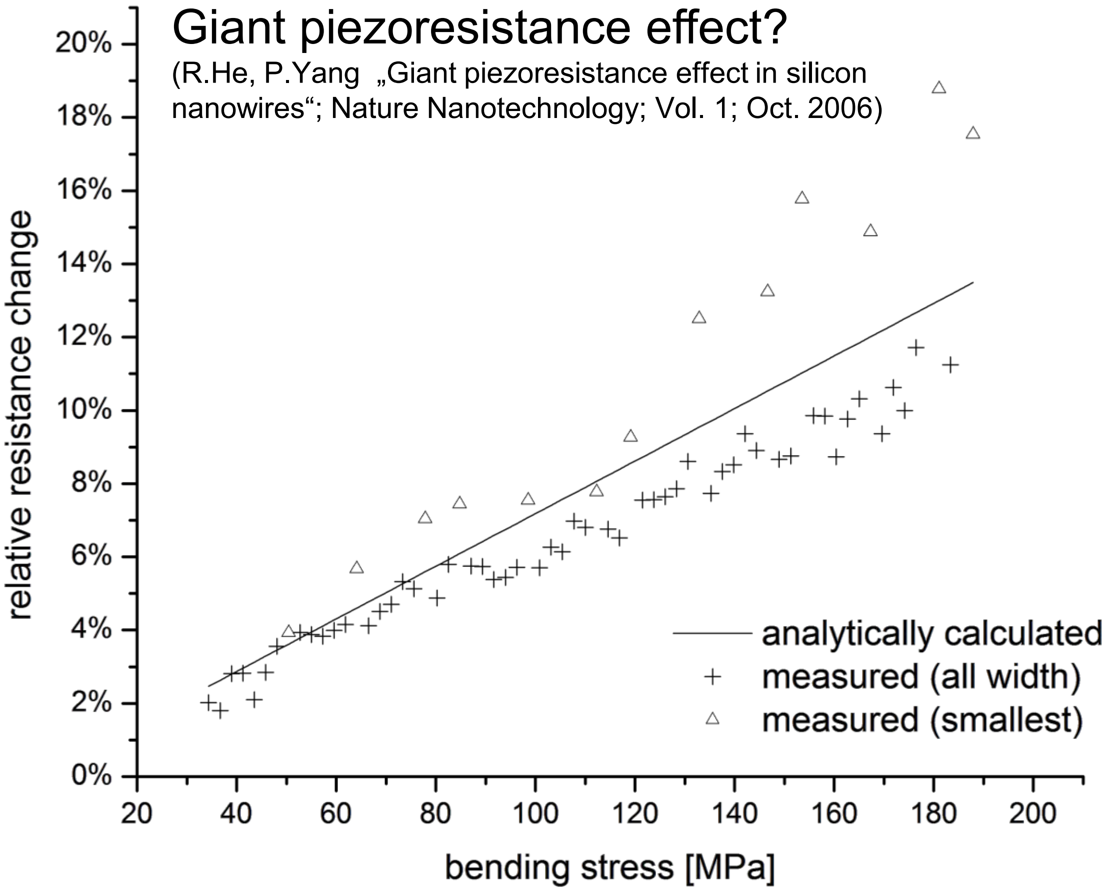
- Resistance change as expected
- Slight deviation from the theoretical value



Electro-Mechanical Characterization

On-Chip Characterization of the PR-Elements

- Significant deviation of the smallest elements
- Possible cause: „Giant piezoresistance effect“
- Effect could be used
  - But large scatter of data



Giant piezoresistance effect?

(R.He, P.Yang „Giant piezoresistance effect in silicon nanowires“; Nature Nanotechnology; Vol. 1; Oct. 2006)

Thermal Characterization

Influence of Thermal Effects on the PR-Effect

- Examination of thermal influences on the PR-elements
- Use of the expanded material model for single crystal silicon
    - Thermal expansion
    - Temperature dependence of resistivity and PR-coefficients

$$\begin{pmatrix} \Delta\rho_{xx} \\ \Delta\rho_{yy} \\ \Delta\rho_{zz} \\ \Delta\rho_{yz} \\ \Delta\rho_{xz} \\ \Delta\rho_{xy} \end{pmatrix} = \rho_0 \begin{pmatrix} \pi_{11} & \pi_{12} & \pi_{12} & 0 & 0 & 0 \\ \pi_{12} & \pi_{11} & \pi_{12} & 0 & 0 & 0 \\ \pi_{12} & \pi_{12} & \pi_{11} & 0 & 0 & 0 \\ 0 & 0 & 0 & \pi_{44} & 0 & 0 \\ 0 & 0 & 0 & 0 & \pi_{44} & 0 \\ 0 & 0 & 0 & 0 & 0 & \pi_{44} \end{pmatrix} \cdot \begin{pmatrix} \sigma_{xx} \\ \sigma_{yy} \\ \sigma_{zz} \\ \tau_{yz} \\ \tau_{xz} \\ \tau_{xy} \end{pmatrix}$$

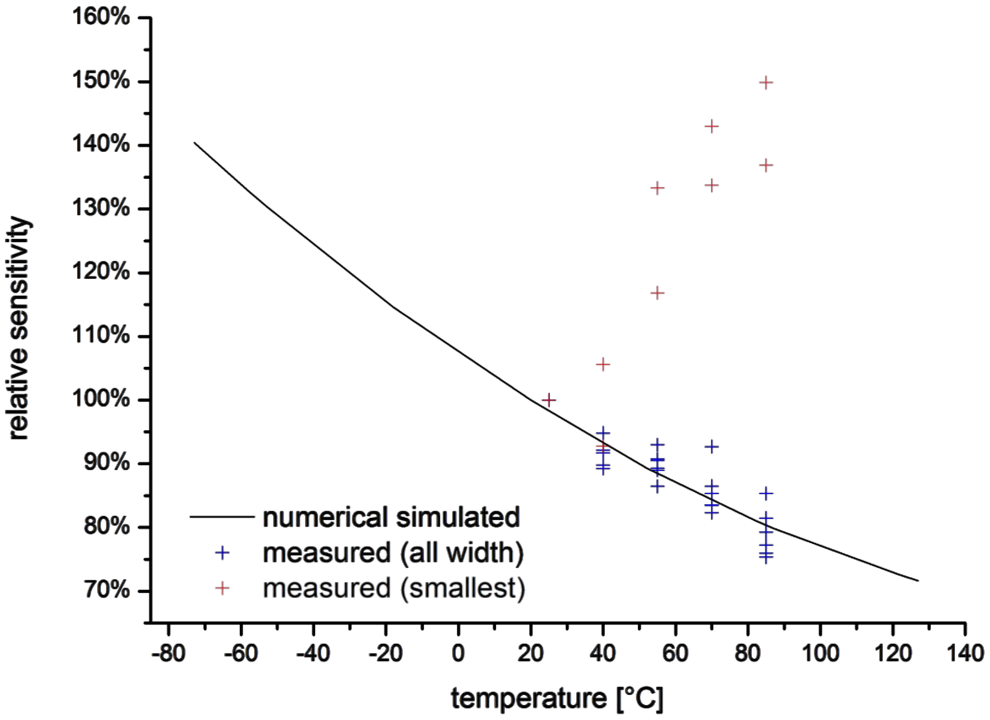
Thermal Characterization

Simulation of Thermal Effects

- Numerical simulation of thermal effects
  - Resistivity
  - Piezoresistive coefficient

→ Significant influence on sensor sensitivity expected

- Simulation confirmed by measurements
- Strange behavior of smallest elements



Summery and Outlook

- Extension of the COMSOL silicon material model with temperature and doping dependences
- Successful use of COMSOL during the development and characterization of a novel high-g accelerometer, e.g.
  - Generating defined mechanical stresses by bending
  - Prediction of thermal influences on sensitivity
- Good agreement between numerical and experimental data

- Outlook
  - Parameter optimization of sensor design with parameter-sweep capabilities of COMSOL
  - Implementation of the giant piezoresistance effect

Thank you for your Attention!

Questions?

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