Parameter Identification of Pressure Sensors at Wafer Level

MEMUNITY-Workshop

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Outline

- **Framework & Motivation**
- **Investigated Pressure Sensor Types**
  - Absolute pressure sensors
  - Relative pressure sensors
- **Wafer Level Testing Approach**
- **Identification Algorithm/System**
  - FE modeling
- **Measurements & Identification Results**
- **Summary & Outlook**

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Framework & Motivation

- BMBF funded project PARTEST (2005-2007)
  - „Measurement and Test Equipment for Determination of Production Relevant Parameters of Microsystems on Wafer-Level“
- Motivation: Significant cost reduction by detection of faulty sensors before the subsequent packaging and assembling steps
- Project partner:

Equipment manufacturers

SÜSS MicroTec

MEMS companies

BOSCH

ELMOS Semiconductor AG

X FAB

Research institutes

Fraunhofer Institut Werkstoffmechanik

Fraunhofer Institut Siliziumtechnologie

Fraunhofer Institut Zuverlässigkeit und Mikrointegration

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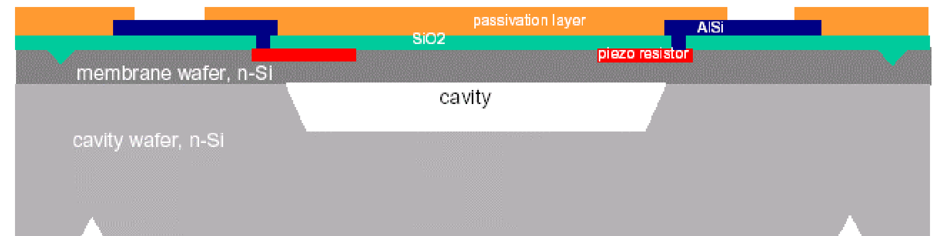
Pressure Sensors

- **Absolute pressure sensors**
  - Technology: backgrinded membrane wafer is bonded on a cavity wafer
  - Quadratic membrane
  - Varying parameter: membrane thickness
- **Relative pressure sensors**
  - 3 varying parameter (x/y membrane size, thickness)



Absolute pressure sensor cross section

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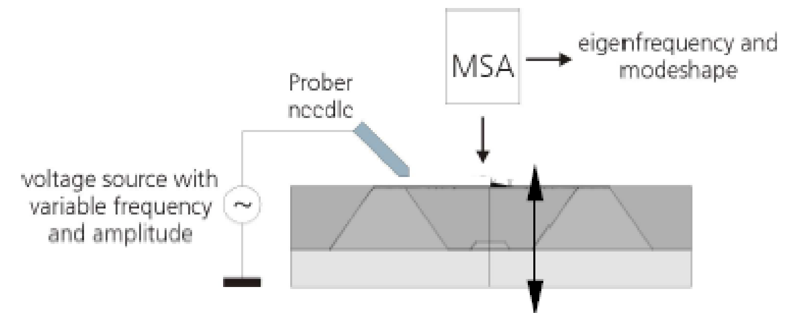
Wafer Level Testing Approach

- Approach: Online parameter identification by optically measured out-of-plane modal frequencies
- Electrostatic excitation of modal frequencies
- FE simulation parameter matrix is basis of identification core
- Two test modi
  - Characterization – close grid of laser measurement points
  - Go/nogo test – minimum number of laser measurement points



Measurement principle

Measurement setup

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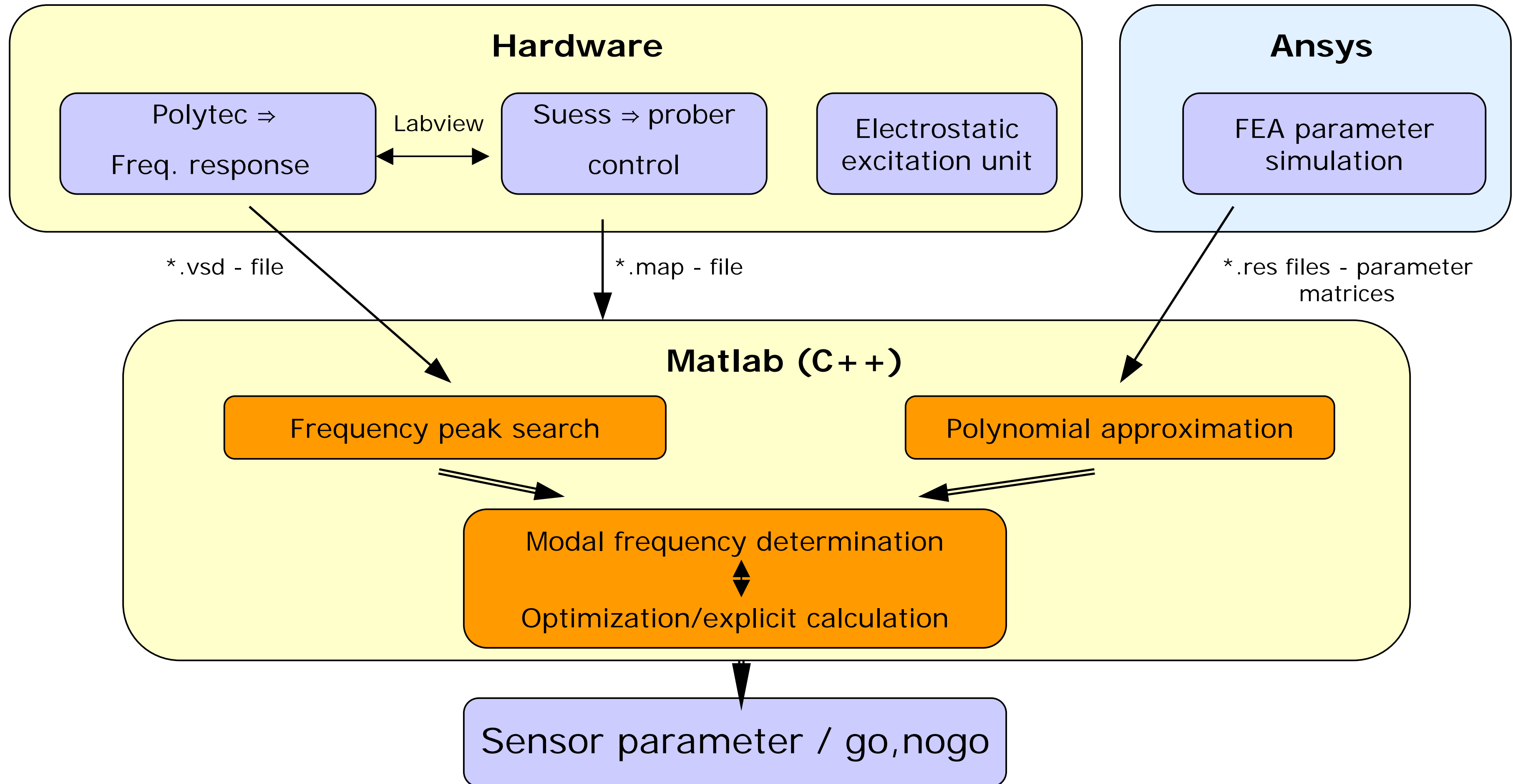
Parameter Identification System



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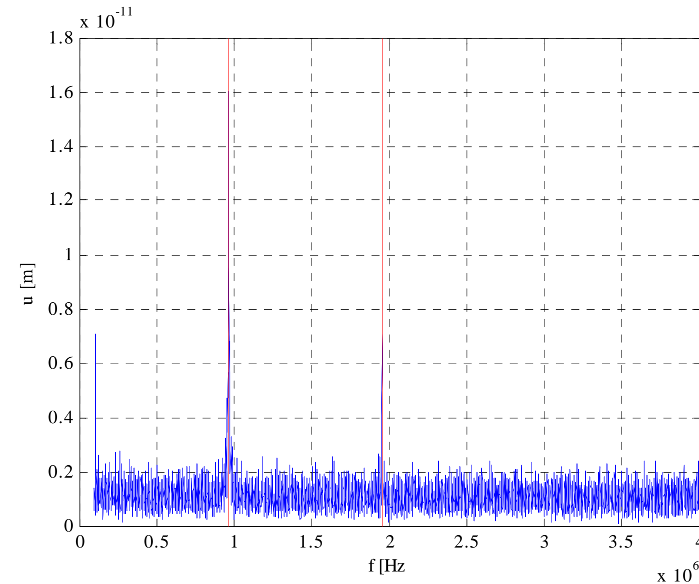
Parameter Identification System II

- **Peak picking**
  - Automatically peak identification by defined minimum/maximum peak width
- **Polynomial approximation**
  - User specified parameters: relative and absolute accuracy
  - Polynomial degree is automatically determined
- **Identification unit**
  - User specified parameter: normed IAE (Identification Accuracy Estimation)
- **Feedback to model/simulation quality**
  - ⇒ Polynomial approximation cannot be reached (including oszillation)
  - ⇒ IAE distribution on wafer follows a function instead of a stocastic distribution



Example of frequency response (absolute pressure sensor, 500x500µm)

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Identification Accuracy Estimation (IAE)

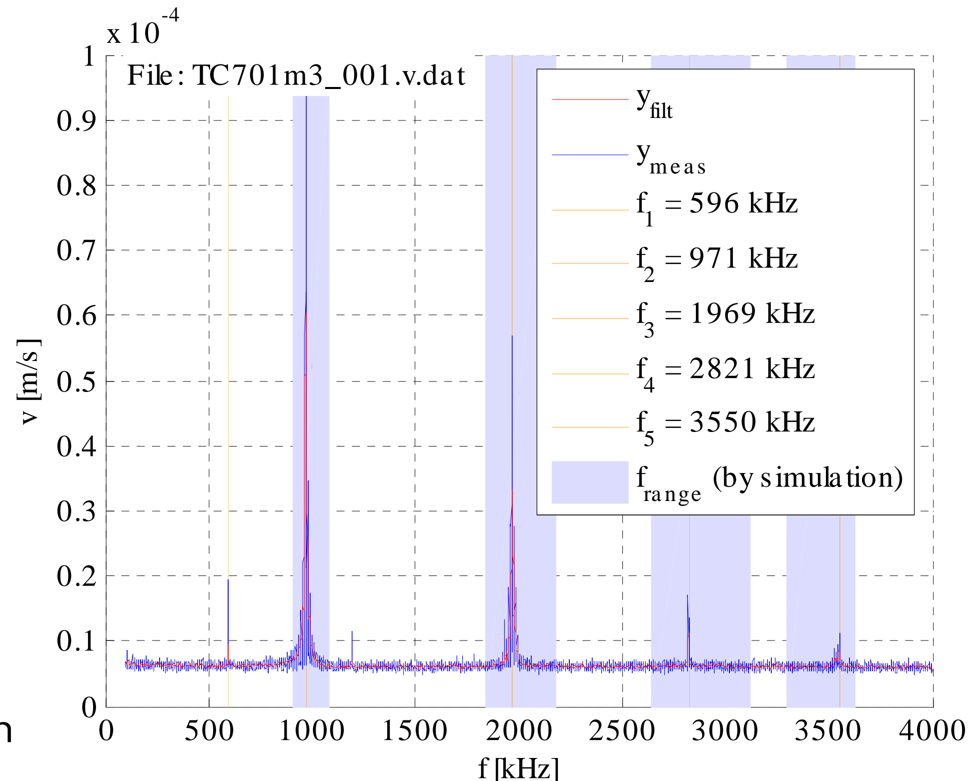
⇒ Introduction of term IAE

- Motivation: detection of
  - **Inaccurate model**
  - **Faulty die**
- Example (absolute pressure sensor): 3 relevant modal frequencies (f_2=971kHz, f_3=1969kHz, f_4=2821kHz)

1 free parameter, 3 modal frequencies ⇒ 3 membrane thicknesses ($z_1 – z_3$)

Identification Accuracy Estimation

$IAE = max(z_i) - min(z_i)$



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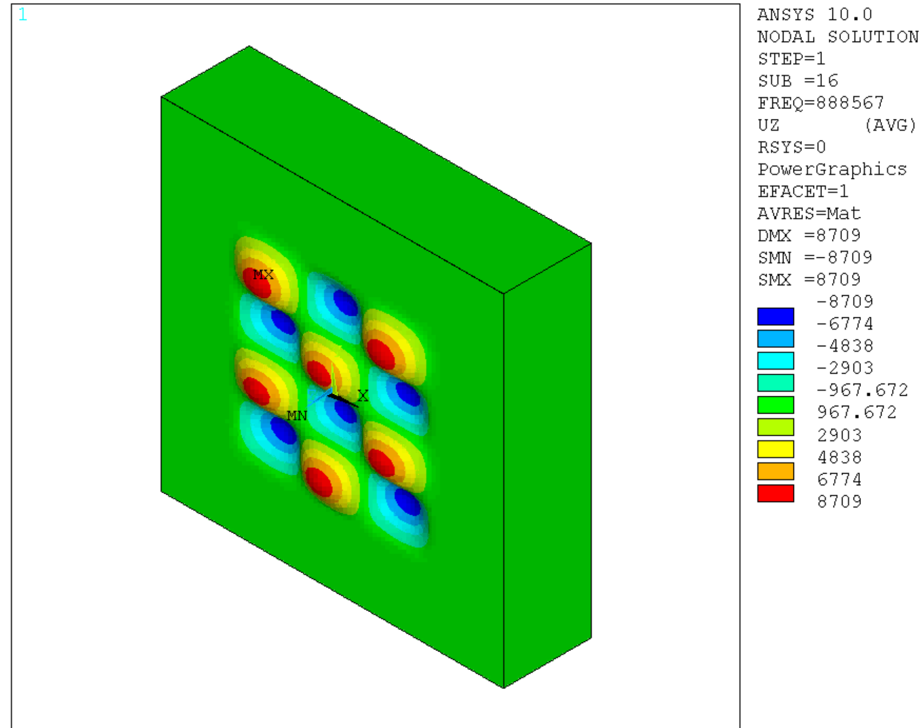
FE Modeling

- Prestressed modal analysis of absolute and relative pressure sensors up to 11th modal frequencies
  - Thermal induced stress
  - Ambient pressure
- Parameter simulations modal frequency versus membrane parameters
- Static analysis including sensitivity calculation



Relative pressure sensor - simulation of the 11th modal frequency

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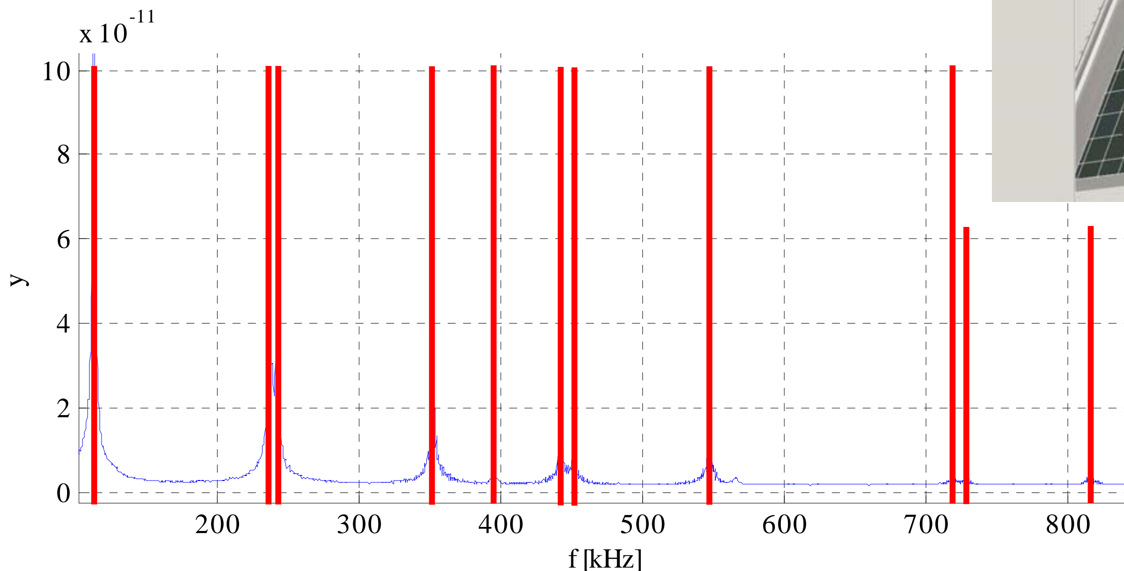
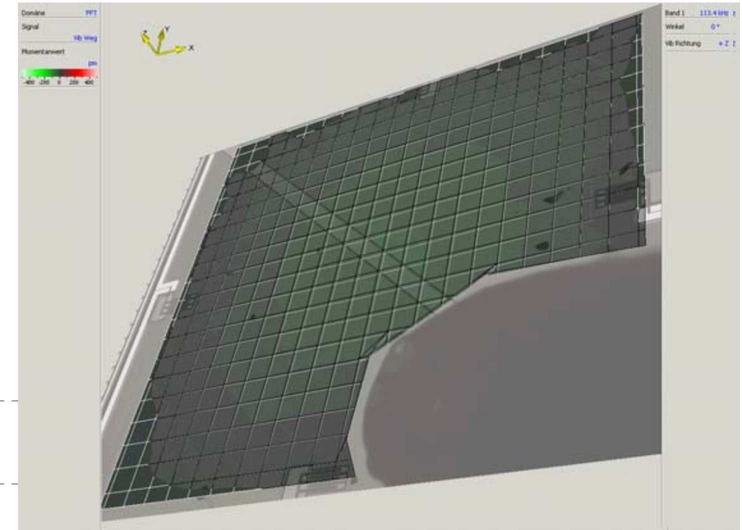
Relative Pressure Sensor Measurements

- Measurement and identification up to 10 modal frequencies





Pressure sensor mode shapes generated by Polytec PSV software

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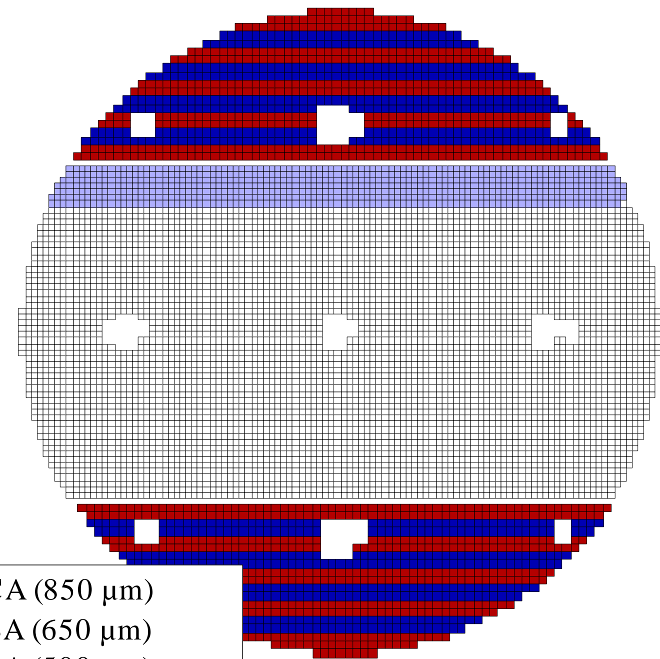
Absolute Pressure Sensor – Parameter Identification

- Absolut pressure sensor with 3 different membrane sizes (500x500, 650x650, 850x850)
- Go/nogo test based on 2 criteria
  - Membrane thickness is within the spec
  - IAE is within the user defined spec (<0.4µm)



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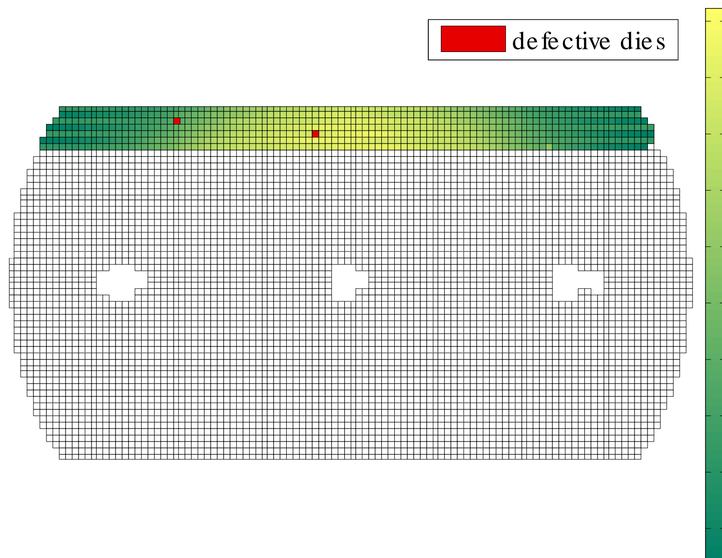
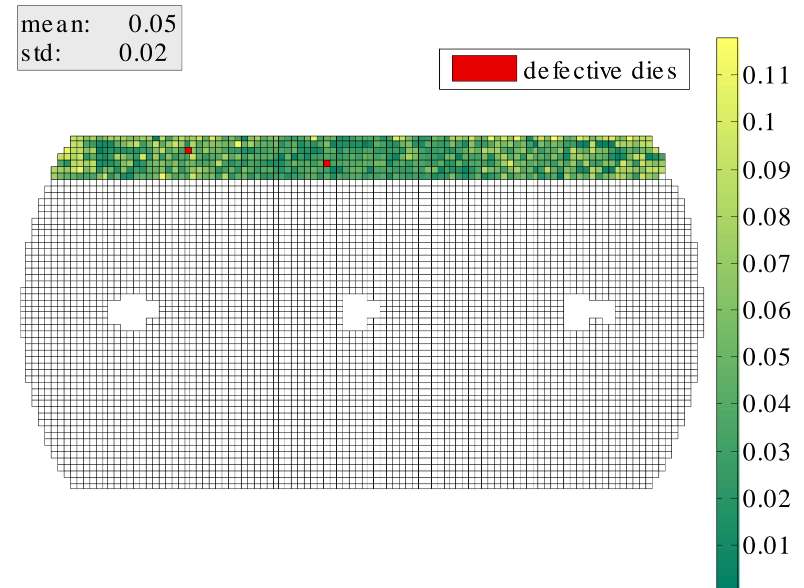
Parameter Identification Results

- Membrane size: 500x500µm



Mean value of identified membrane thicknesses



Difference between the largest and the smallest identified membrane thickness (IAE in microns)

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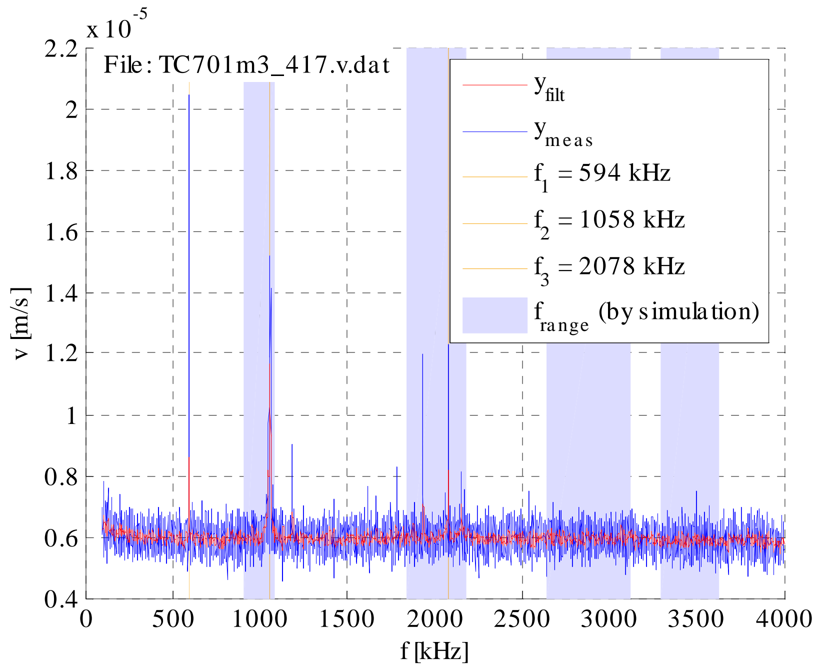
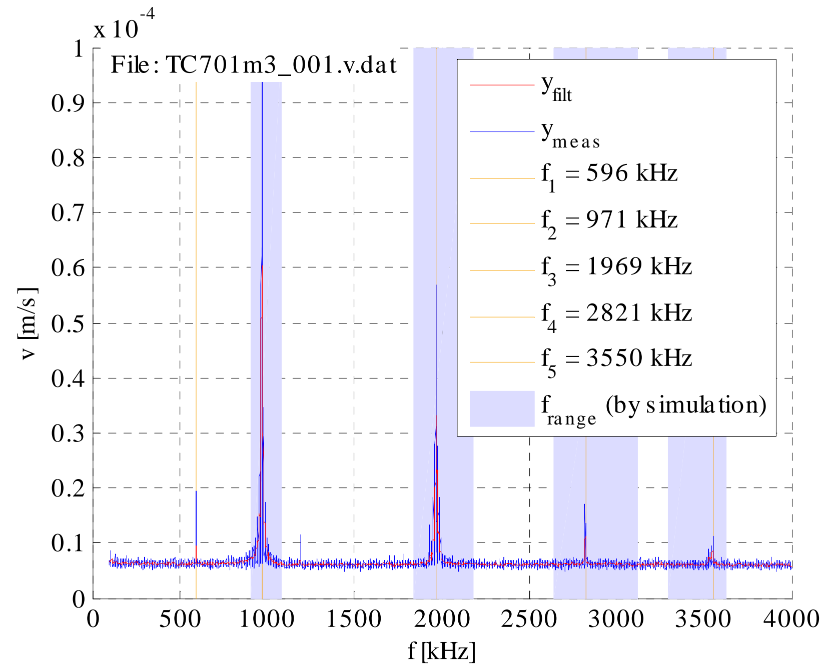
Parameter Identification Results

- Usage of IAE to identify wrong dies



Die marked by identification as irregular



Regular die

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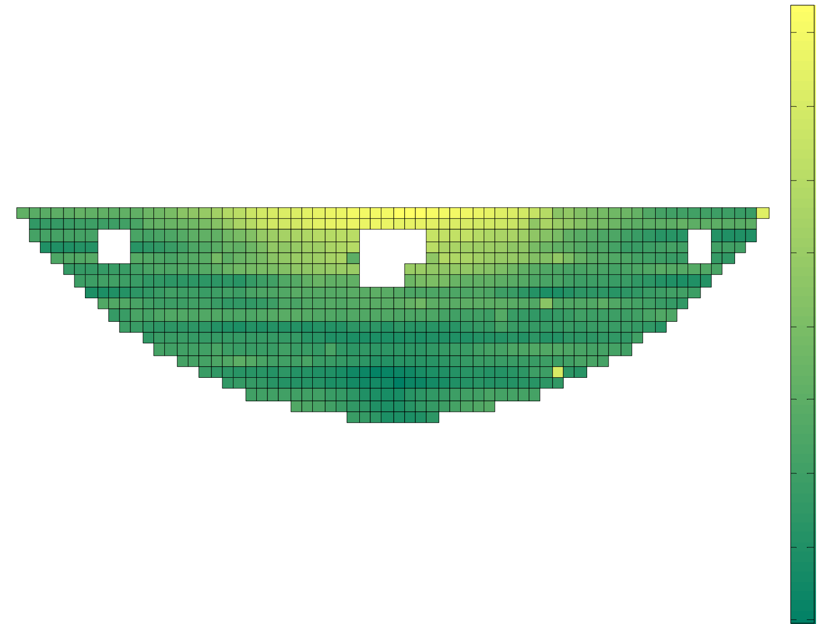
Parameter Identification Results

- IAE of sensor types
  - 500x500µm: 110nm
  - 650x650µm: <300nm
  - 850x850µm: <400nm
- Result: model improvement of larger membranes
  - Optimization of prestress parameters



Mean value of identified membrane thicknesses (membrane size 650x650 and 850x850)

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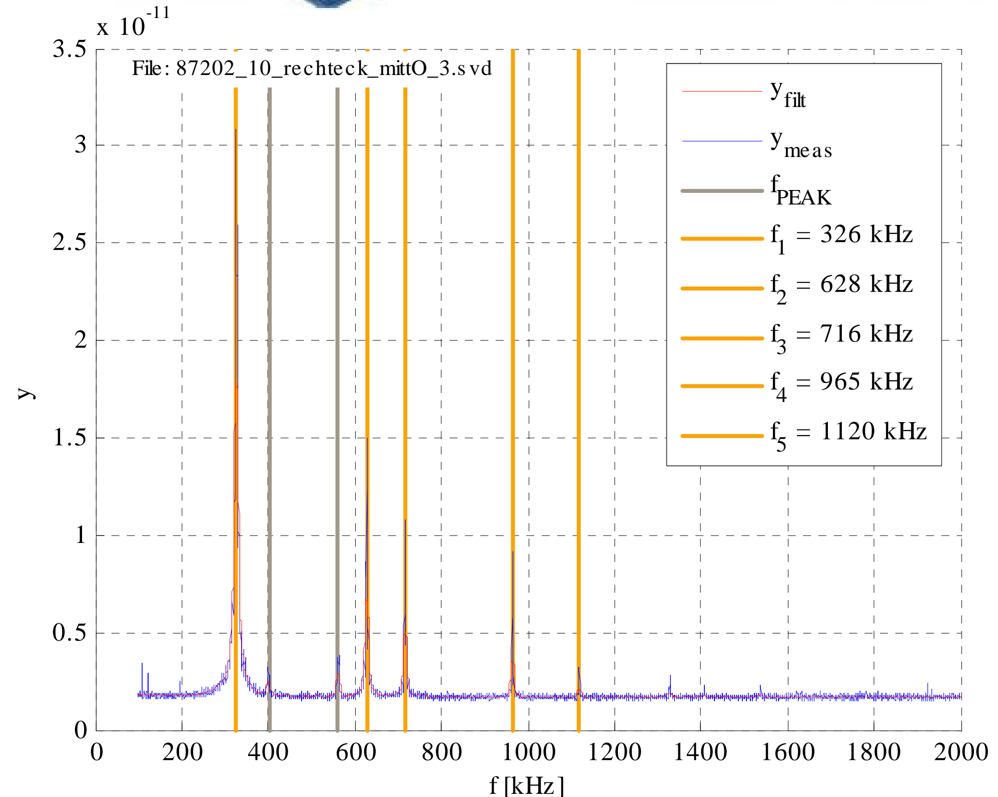
Parameter Identification of Rectangular Membranes

- Absolute pressure sensor test structures with rectangular membranes
- Varying parameters:
  - Membrane thickness (15-25µm)
  - Membrane size in y (800-900µm, Note: x size is fixed)
- Note: Peaks are not obligatory modal frequencies!
- Result:
  - X = (811.0 µm, 18.09 µm)
  - *IAE* = (6.4 µm, 0.26µm)



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Parameter Identification of Relative Pressure Sensors

- **Usage up to 8 modal frequencies for the identification of 3 sensor parameters.**

Die number	1	2	3	4	5
Membrane thickness	14.2	13.97	14.10	14.54	13.56
IAE	0.27	0.26	0.17	0.22	0.32
X size	1302.1	1298.2	1303.1	1295.3	1302.1
IAE	4.2	9.1	12.2	13.1	8.3
Y size	1304.2	1306.3	1302.1	1298.4	1299.3
IAE	5.2	8.9	5.9	11.2	12.1

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- Summary
  - Vibrometer, prober and excitation unit permits the optical measurement of modal frequencies up to 2.5 MHz
  - Automatic online identification of up to 3 pressure sensor parameters within 3 seconds
- Outlook
  - Static measurements of deformation and sensitivity – correlation of dynamic and static identification results
  - Expansion of the approach to further sensor types (e.g. stress identification of IR sensors)
  - Sensitivity analysis
  - Reduction of measurement time to 1 second (software/hardware)

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