Reliability assessment of brittle MEMS structures based on FE- simulation, size effect theory and probabilistic sampling

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Motivation

- **reliability orientated, numerical design** of brittle materials structures for microelectromechanical systems **not yet established**

- based on **Weibull parameters from tests** on „simple“ test structures and the **size effect theory** a reliability assessment for more complex structures is possible

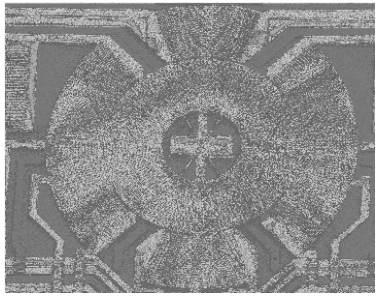
- but **complex structures** have **deterministic parameters** in the design process

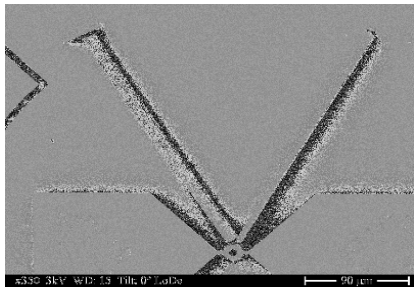
- **variances of structural parameters are not considered**

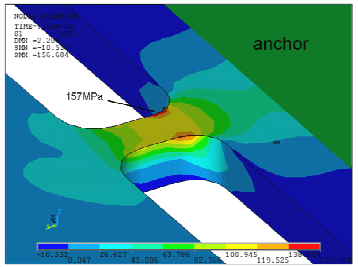
- geometrical parameters (thickness of layers, shape of cross section) material parameters (e.g. Young's Modulus) or pre-stresses (e.g. from thin layers)

- **sensitivities of structural properties** (like deformation, eigenfrequencies) in dependence of structural parameters are yet not investigated

Procedure of design for reliability of polysilicon structures

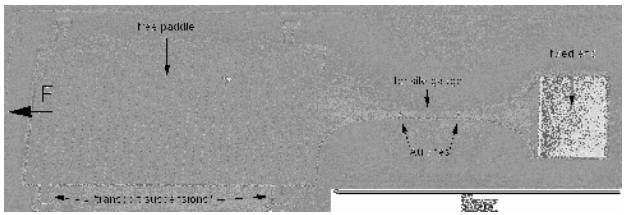


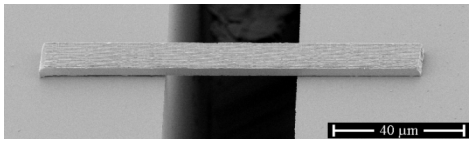




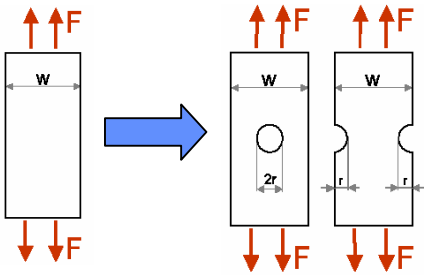
(4) Hauck et al.

Objective: Strength and reliability assessment for load cases of complex structures in the design or „redesign“ process

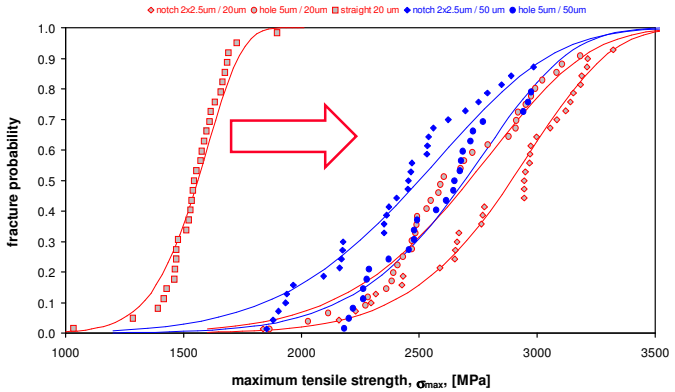




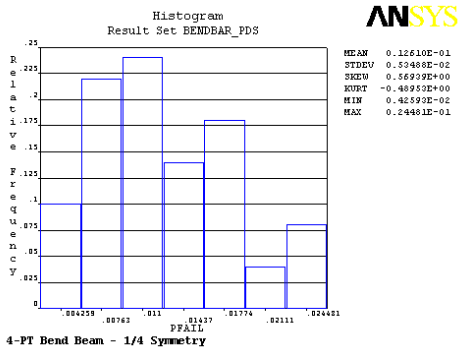
Strength test on „simple“ mechanical systems



(1) Bagdahn et al.



Weibull- Plot of strength



Histogram $p_{failure}$

Weibull- Theory, Size effect theory and Probabilistic design

JHU

freescale semiconductor

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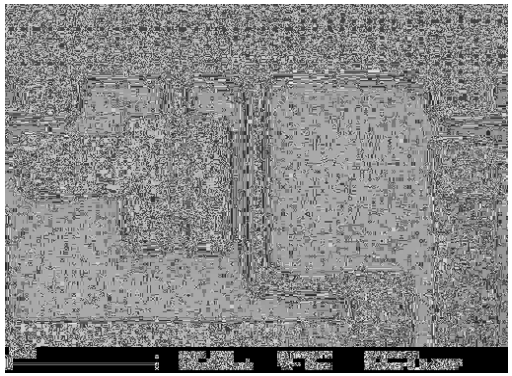
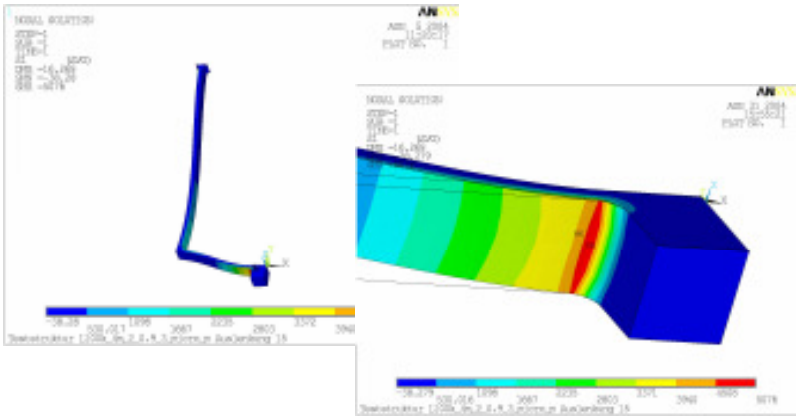
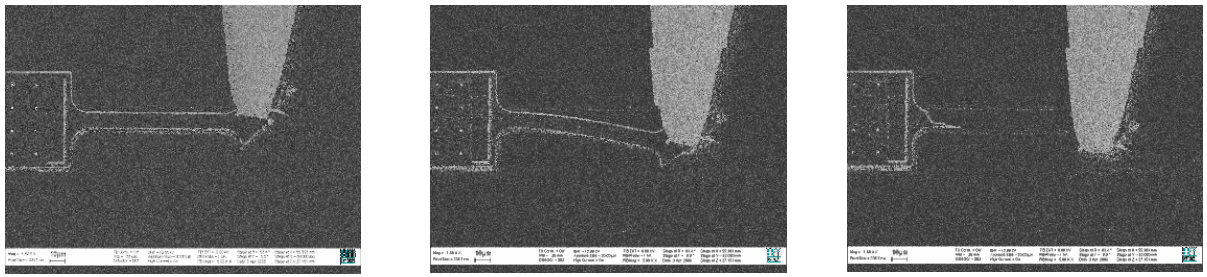
Strength test on „simple“ mechanical systems

- probabilistic strength analysis based on the Weibull theory
- measurement of forces or displacements on test structures with simple mechanical systems
- mechanical systems: 3pb, 4pb, tensile (straight, notched, holed), also on free cut parts of the original structure
- need for numerical simulation with FE-models to get the stress values
- determination of Weibull parameters

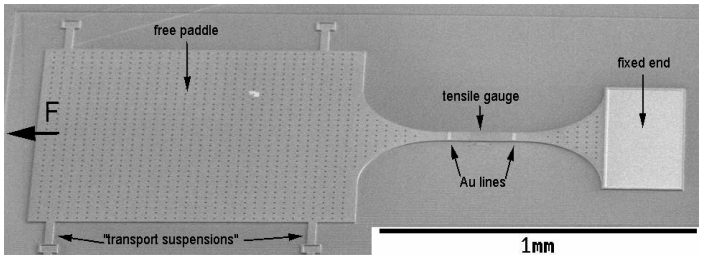






Bending test with FIB manipulator

(1) Bagdahn et al.



(2) Boroch et. al.

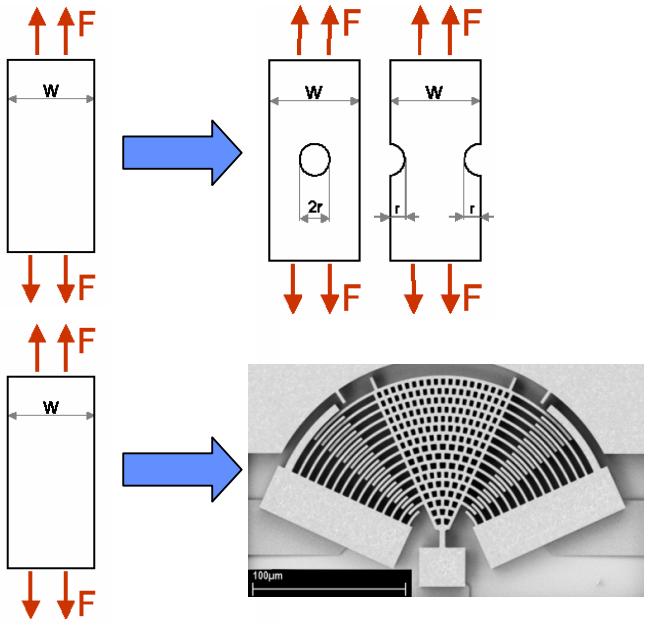
Size effect theory and Probabilistic design

- strength assessment of complex components in design or redesign based on size effect theory of the described tests

- using Cares/Life software: time (in)dependent reliability of brittle structures, originally from NASA

- different theories to calculate effective units and scale parameters (based on FE- models)

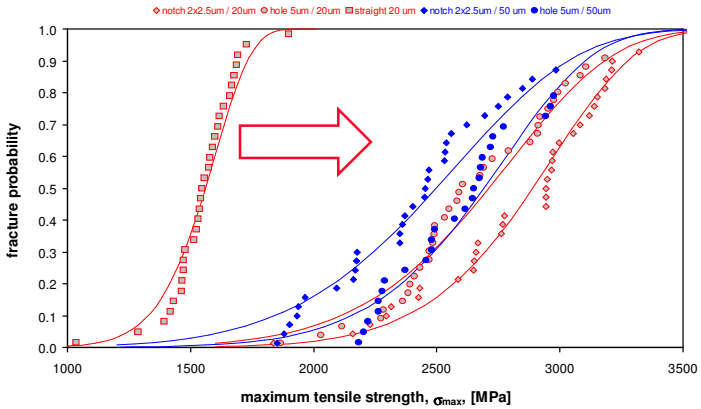
- reliability calculation with ANSYS PDS and Cares/Life



Size effect

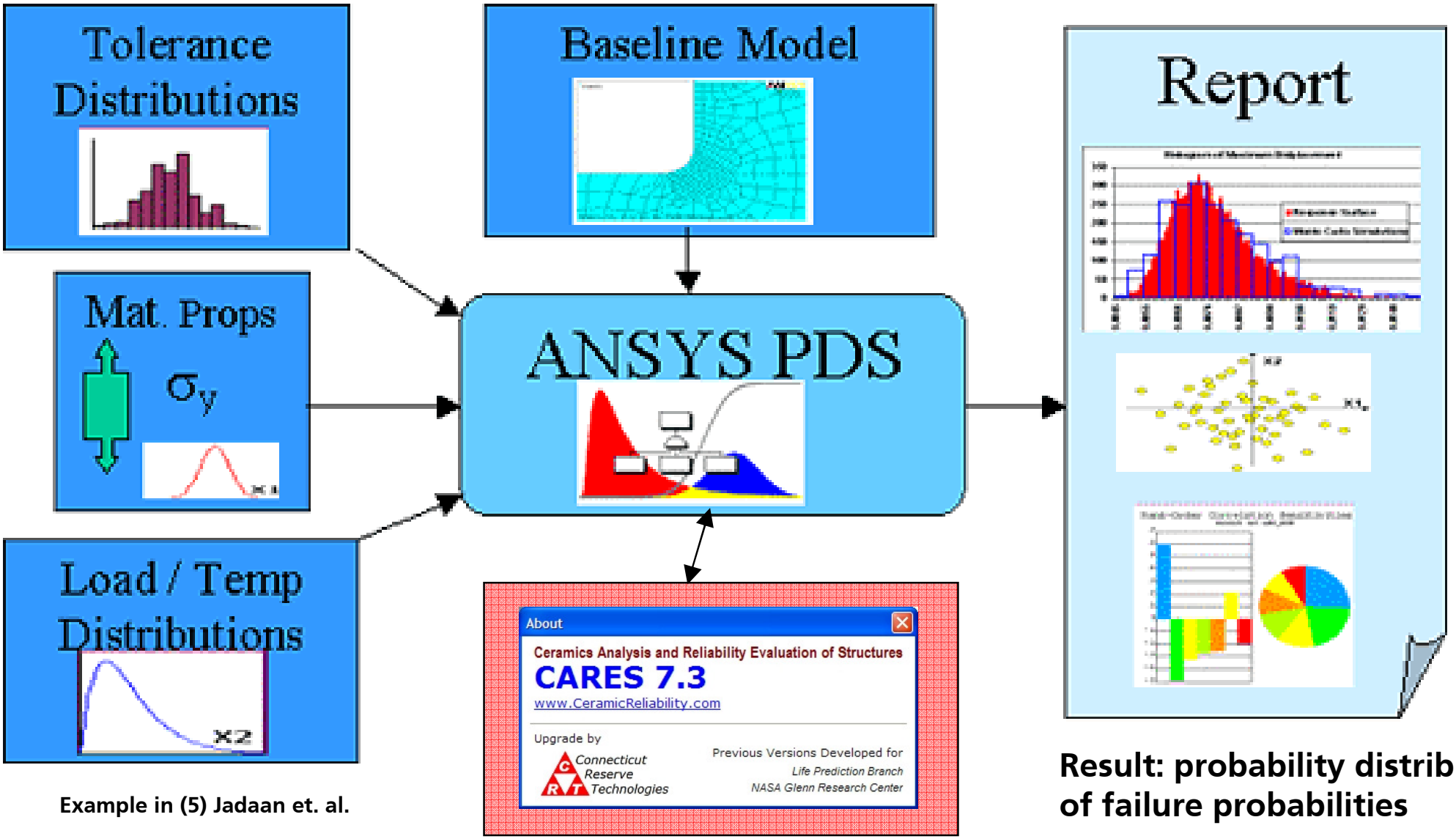
$\sigma_{\theta c} = (1/V_e)^{1/m} \sigma_{0v}$ or $\sigma_{\theta c} = (1/A_e)^{1/m} \sigma_{0A}$

V_e or A_e are the effective volume or area,
σ_{0A} or σ_{0A} are the scale parameters
("material-process" parameter)



(1) Bagdahn et al.

ANSYS Probabilistic Design System- PDS



Example in (5) Jadaan et. al.

Result: probability distribution of failure probabilities

http://www.ceramicreliability.com/

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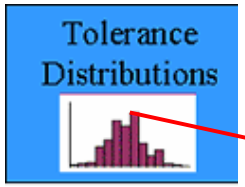
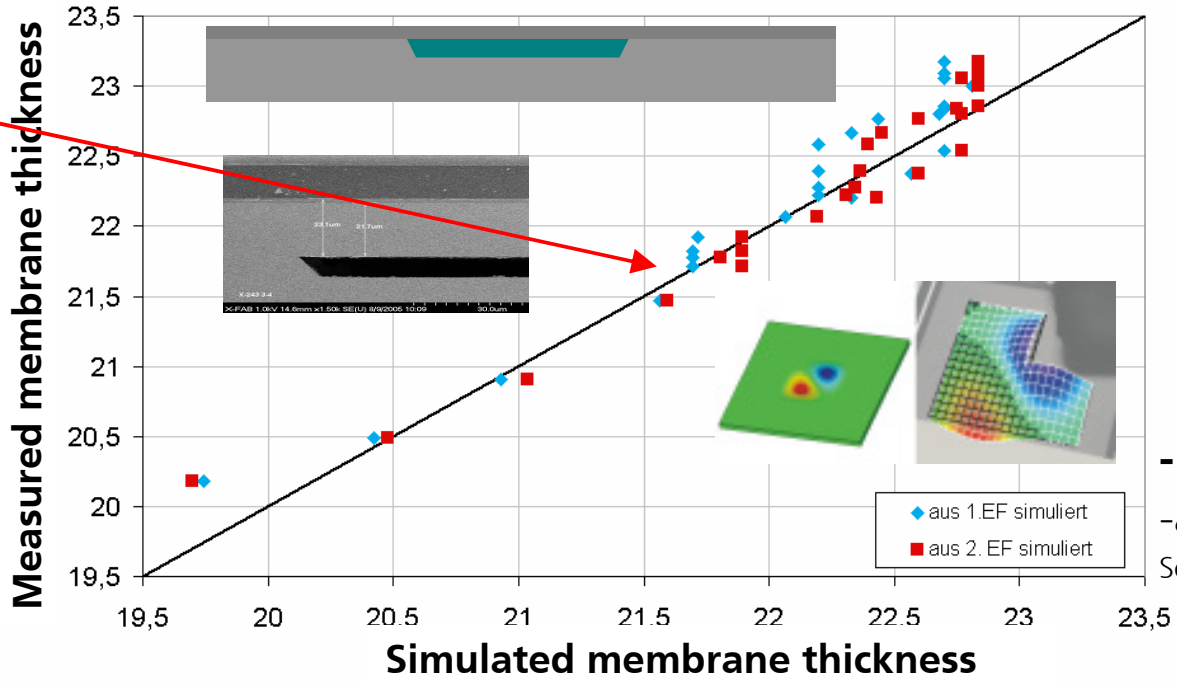
Pictrure from
http://padtinc.com/epubs/focus/

A way to get parameter distributions

Dynamic Characterisation of silicon MEMS
Example: Parameter identification of 25 silicon membranes





(3) Ebert et. al.

- Polytec MSA 400 with SUSS Prober
-at the institute since 10/2006

Source: Polytec

- important influence of the used "known" parameters for the reliability investigations
- new methods in development to characterize MEMS parameters (such pre-stress, pre-deformation, material, geometry)

http://www.memunity.com/par-test.htm

Some literature to the topic

(1) J. Bagdahn, W. N. Sharpe, Jr., and O. Jadaan, **Fracture strength of polysilicon at sress concentrations**, **Journal of Microelectromechanical Systems**, Vol. 12, No. 3, 2003, 302-312.

(2) R. Boroch, J. Wiaranowski, R. Mueller-Fiedler, M. Ebert, J. Bagdahn (2007) **Characterization of strength properties of thin polycrystalline silicon films for MEMS applications,** ***Fatigue & Fracture of Engineering Materials and Structures*** 30 (1), 2–12.

(3) Ebert, M.; Gerbach, R.; Bagdahn, J.; Michael, S.; Hering, S.: **Numerical identification of geometric parameters from dynamic measurement of grinded membranes on wafer level,** in Proceedings of 7th International Conference on Thermal, Mechanical and Multi-Physics Simulation and Experiments in Micro- Electronics and Micro- Systems (***EuroSimE***), L.J. Ernst et al. (Eds.), Como, Italy (2006) 208-213

(4) Hauck, T.; Li, G.; McNeill, A.; Knoll, H.; Ebert, M.; Bagdahn, J.: **Drop simulation and stress analysis of MEMS devices,** in Proceedings of 7th International Conference on Thermal, Mechanical and Multi-Physics Simulation and Experiments in Micro-Electronics and Micro- Systems (***EuroSimE***), L.J. Ernst et al. (Eds.), Como, Italy (2006) 203-207

(5) Jadaan et al.: „**Reliability of high temperature lightweight valve train components in a total probalistic design environment",** Proceeding of the 30th International **Conference on Advanced Ceramics and Composites**, Developments in Advanced Ceramics and Composites, USA, 2006