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Modeling the Thermally Induced Curvature of Multilayer Coatings with COMSOL Multiphysics™

COMSOL CONFERENCE 2008 HANNOVER

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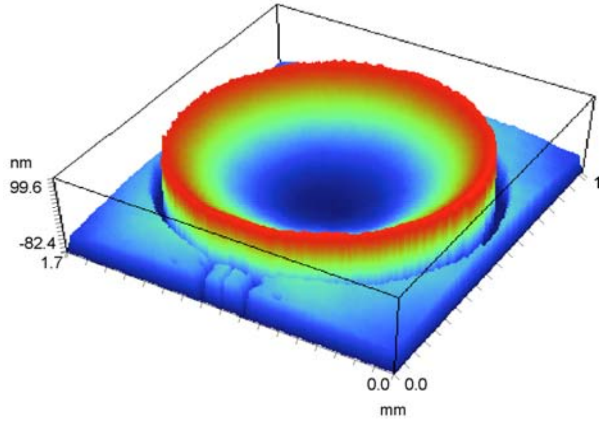
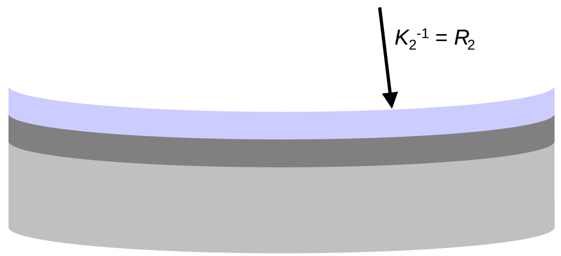
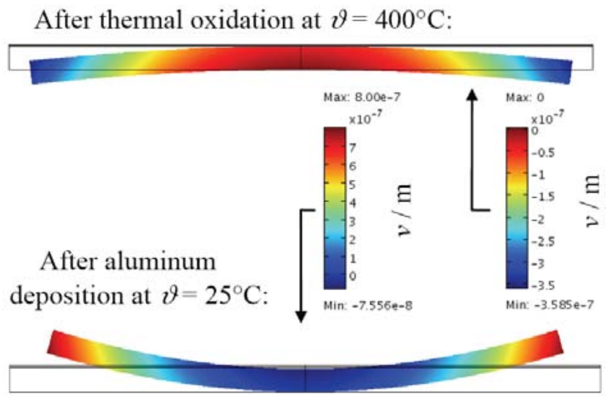
Outline

- Introduction
- Problem description
- FEA Requirements and Problem Solving in COMSOL
- Implementation of *birth and death* in COMSOL
- Results
- Summary and Outlook







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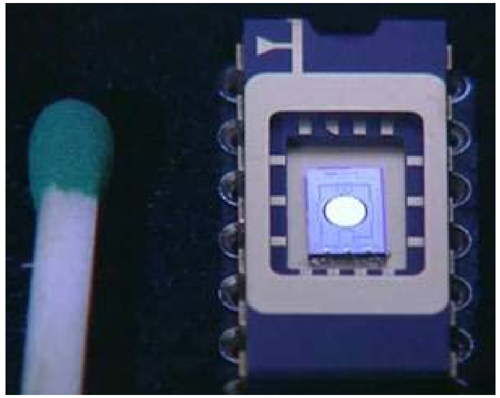
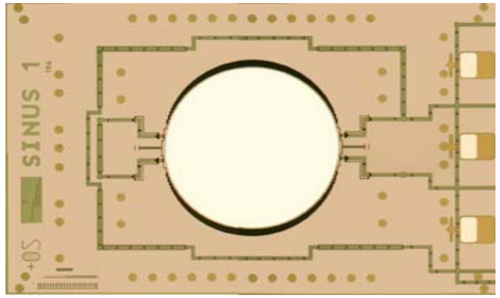
Introduction

Example: Multilayered Coatings for Micro Mirros:





1) Metallic mirrors: protected Ag, Au

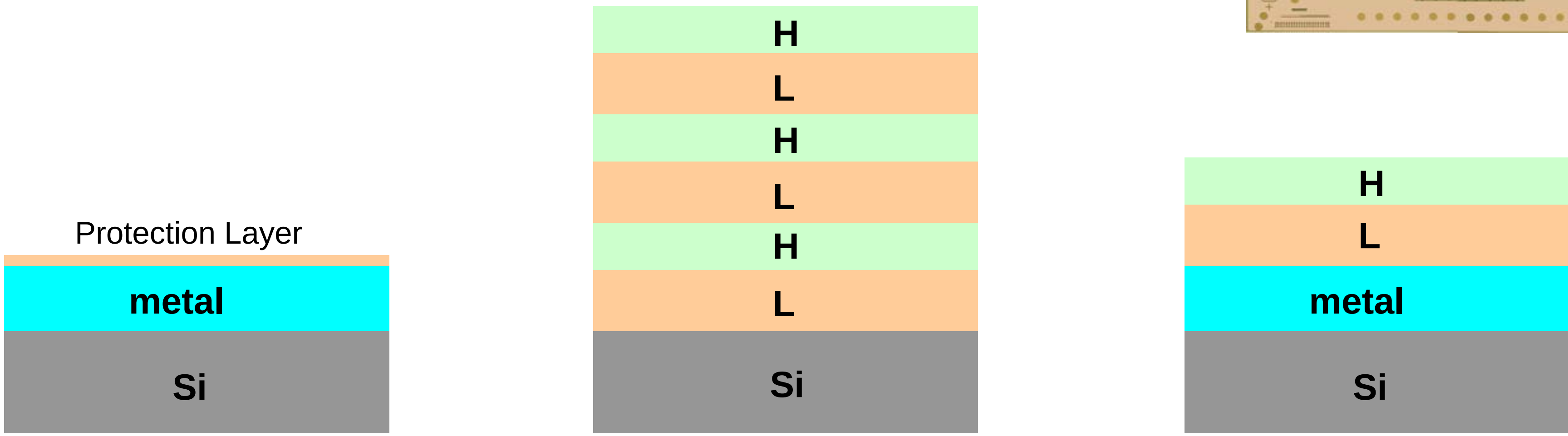
⇒ *HR-broadband HR-NIR-reflectors*

2) Dielectric multilayer: @ 1064nm (Nd-YAG laser)

⇒ *high power applications*

3) Enhanced metallic : @ Hybrid me*tallic / dielectric-Bragg* design

⇒ *high power applications for NIR / VIS / UV*



1) metallic **2) dielectric** **3) enhanced metallic**

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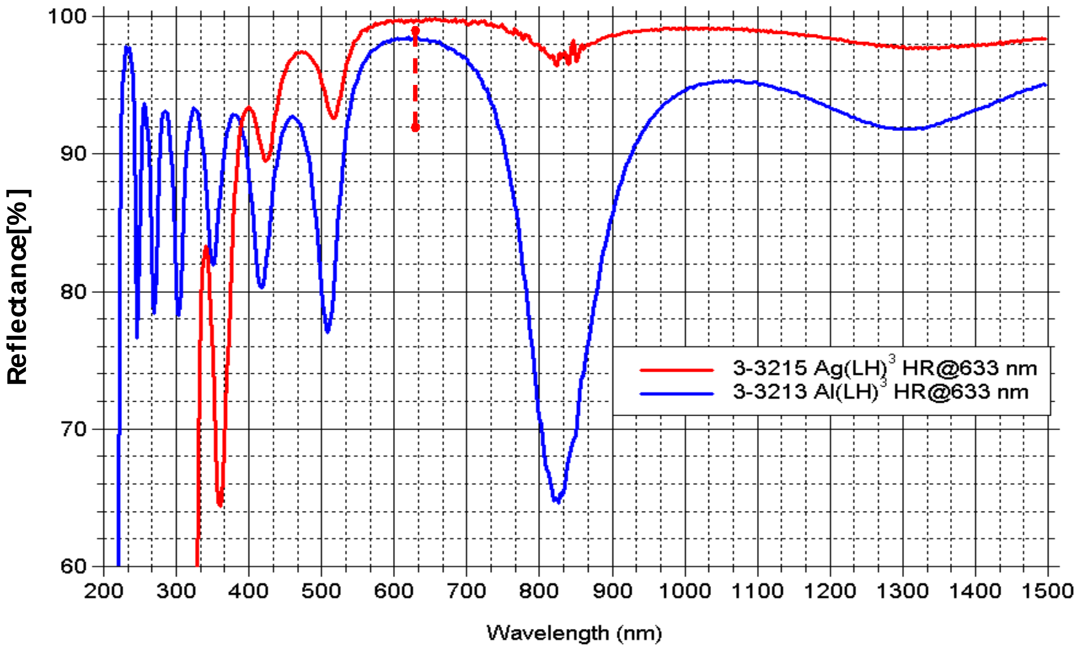
Introduction

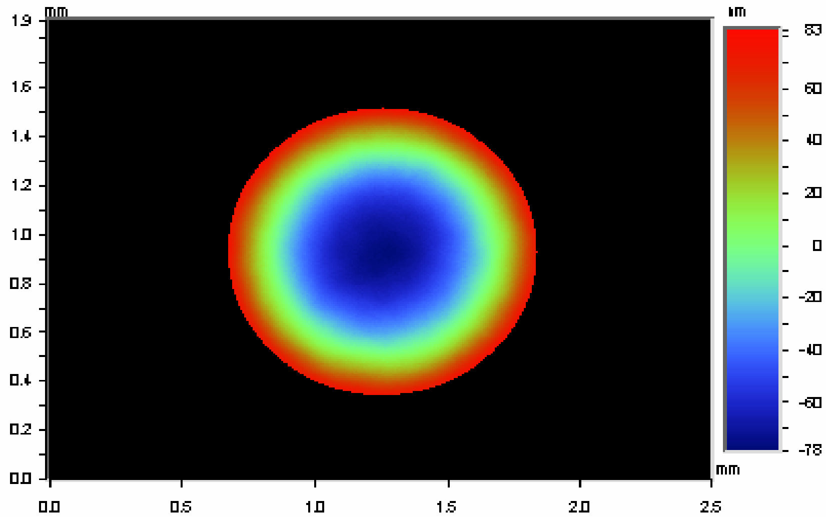
Design: **Al/(SiO_2/HfO_2)^3**
R @ 633 nm: 98.5 %
Total thickness: 620 nm

Design: **Ag/(SiO_2/HfO_2)^3**
R @ 633 nm: 99.7 %
Total thickness: 640 nm



2) dielectric

UV-HR Design:
Al/(SiO_2/HfO_2)^3
R_{curv} = 1,12m



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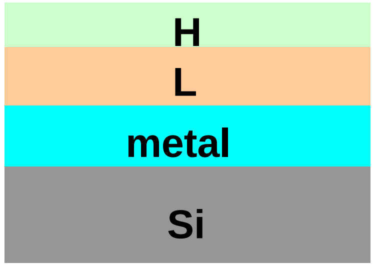
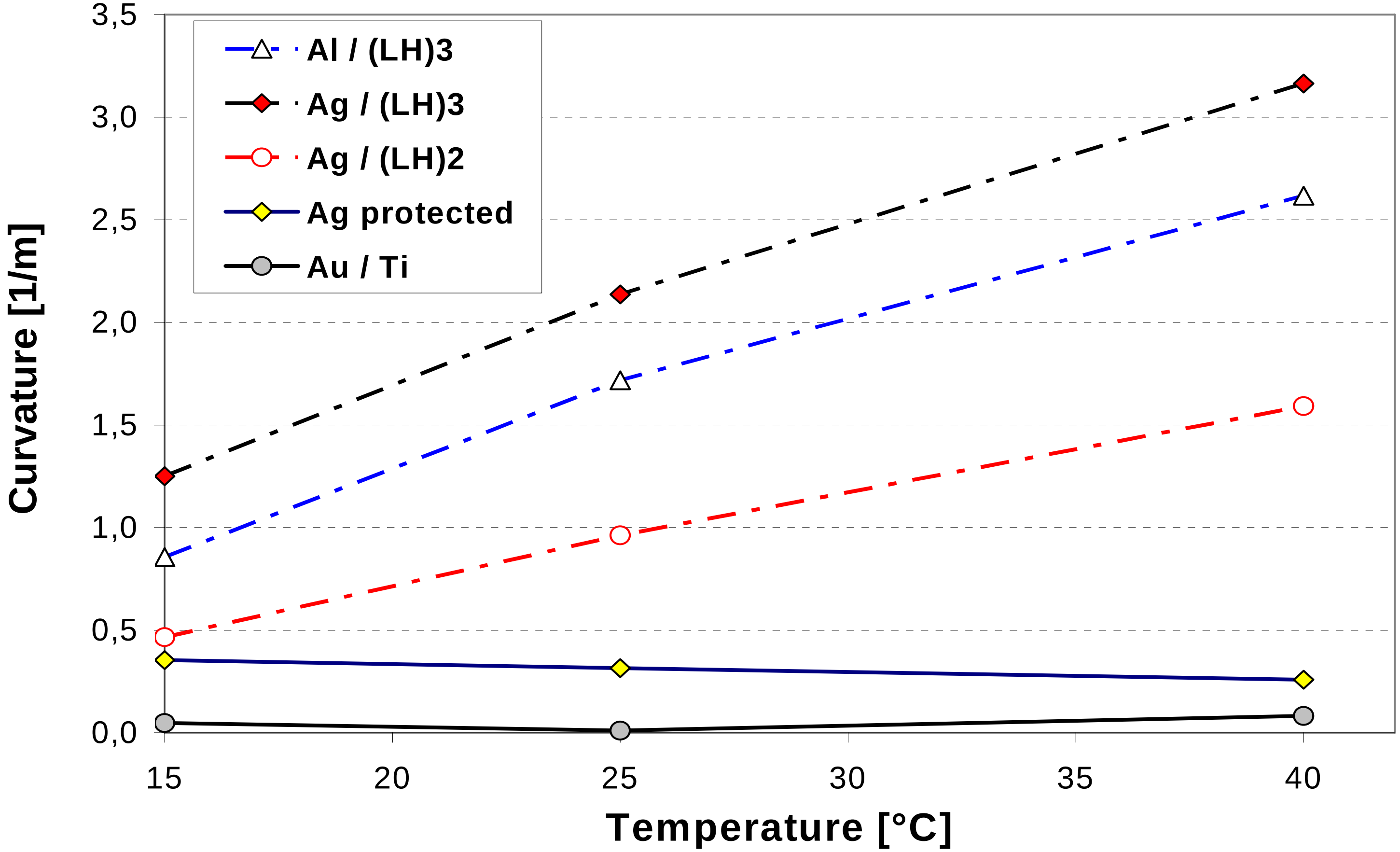
Introduction

Temperature dependence of mirror planarity

Asymmetric design



e.g. *hybrid NIR-HR*



- **A well understanding of curvature generation is essential for mirror flatness**

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Introduction

- Calculating the **thermally induced curvature of multilayer plates**:
  - analytical: two layer case: Timoschenko (1925)
    multilayer case: Vasudevan, Johnson (1962)

ON MULTI-METAL THERMOSTATS

by M. VASUDEVAN and W. JOHNSON

Mechanical Engineering Department, Manchester College of Science and Technology
Manchester, England.

Summary

An elastic analysis of bi-metal thermostats has been made by Timoshenko[1]). The effect of having more than two metals, on the performance characteristics of a thermostat of the same total thickness as the bi-metal one, has not received attention. The performance characteristics of a thermostat such as temperature of cut-off, the temperature of cutting-in and sensitivity depend upon the radius of curvature to which a composite strip

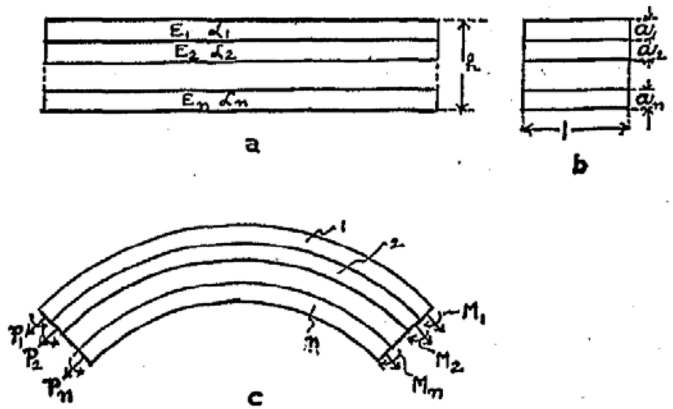

Fig. 1. Multi-metal strip under uniform heating.

- spherical curvature: small deflections max(w) < h

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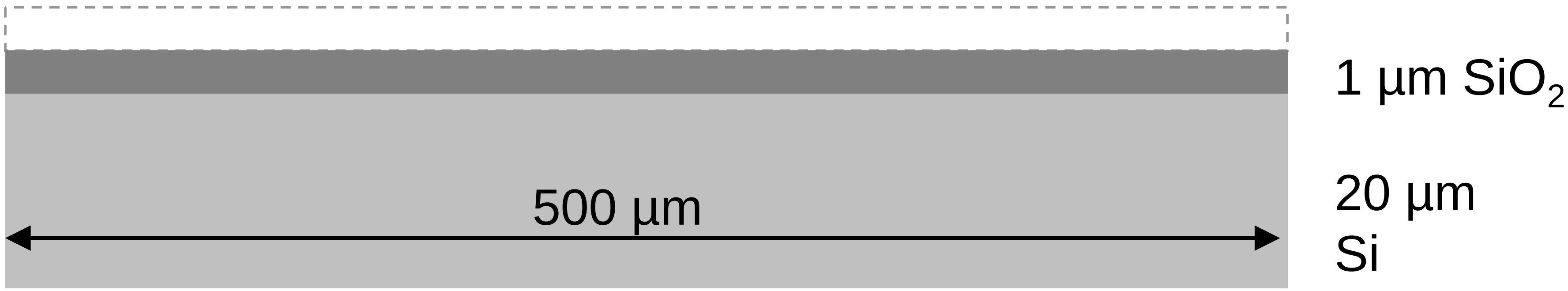
Problem description

- **1. Step:** Heating the silicon plate to oxidation temperature and thermal grow of SiO_2:



$\vartheta = 900°C$

Si SiO_2

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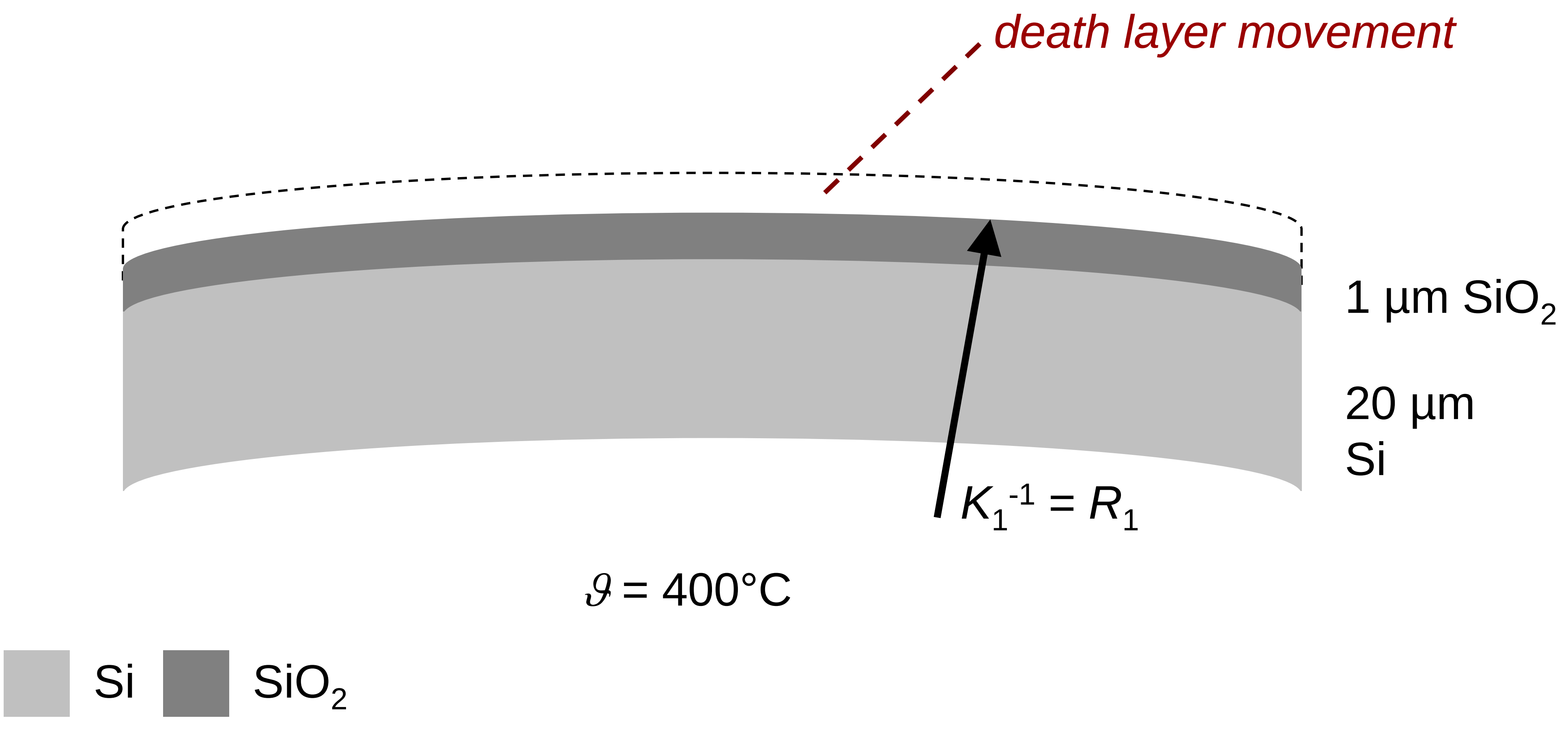
Problem description

- **2. Step:** Cooling down the stack:



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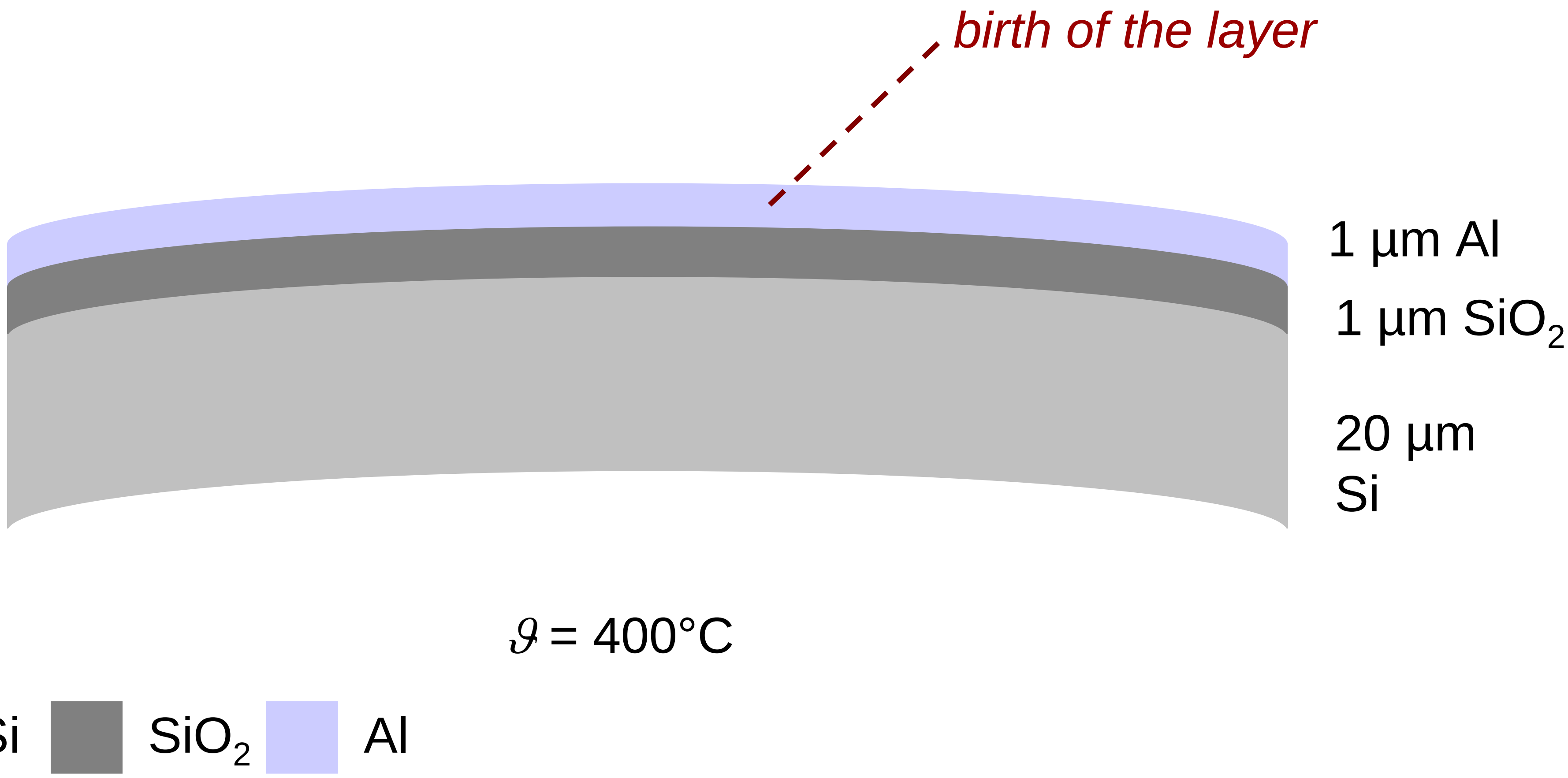
Problem description

- **3. Step:** Evaporation of Al on bended substrate:



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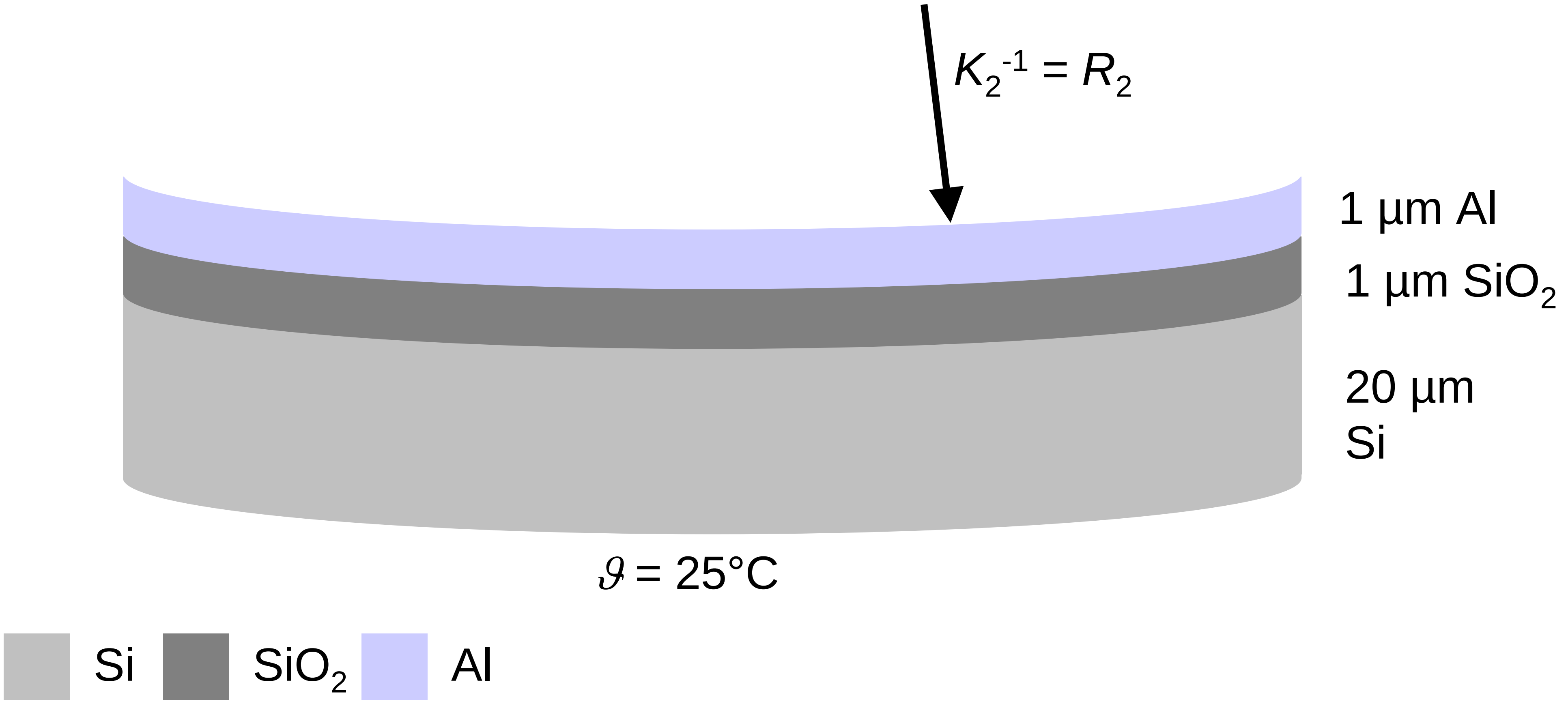
Problem description

- **4. Step:** Cooling down to room temperature:



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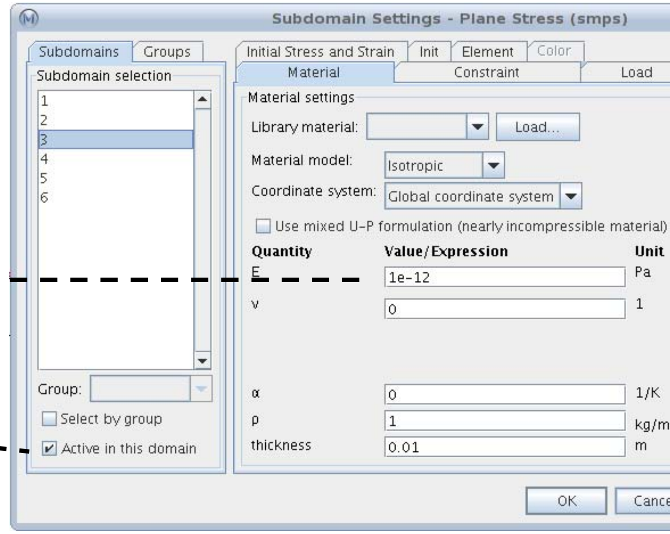
FEA Requirements and Problem Solving in COMSOL

- Layer deposition on deformed surfaces:
  - *Birth and Death* is required:
  - *Death*: low YOUNG's Modulus (e.g. 10^{-12} Pa)
    not: active in this domain
  - *Birth*: reset the YOUNG's Modulus



- Multiple simulation steps:
  - multiple application modes
  - stepwise solving (requires script for better handling)

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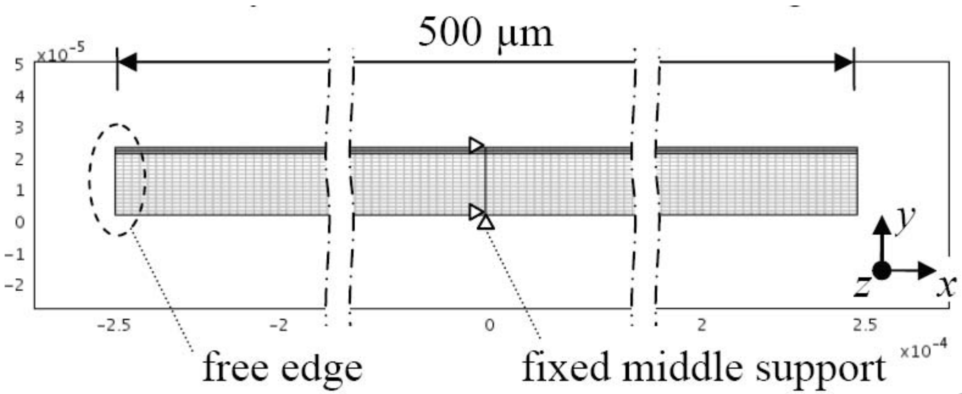
Implementation of *birth and death* in COMSOL

- 2 x Plane Stress application modes
  - dealing with the same geometry and bc



- Birth and Death
- Strain / stress coupling
  - superposition of non thermal stress is possible

parameter	application modes			sub-do-main
	smps	smps2	…	
Material *E* / Pa *Temp*	… 10^{-12} Pa *Tempref*	… 10^{-12} Pa *Tempref*	…	…
Material *E* / Pa σ_{xi} / Pa σ_{yi} / Pa σ_{zi} / Pa *Temp* *Tempref*	- 10^{-12} - - - 400 °C 400 °C	**Al** $70 \cdot 10^{9}$ -*ex_smps* ·70e9 -*ey_smps* ·70e9 -*ez_smps* ·70e9 25 °C 400 °C	…	3
Material *Temp* *Tempref*	**SiO_2** 400 °C 900 °C	**SiO_2** 25 °C 900 °C	…	2
Material *Temp* *Tempref*	**Si** 400 °C 900 °C	**Si** 25 °C 900 °C	…	1

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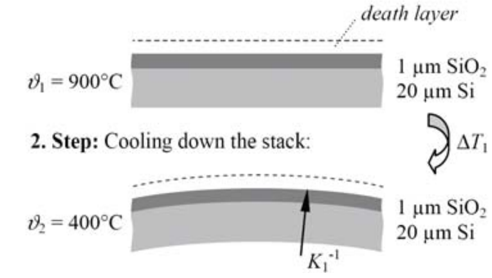
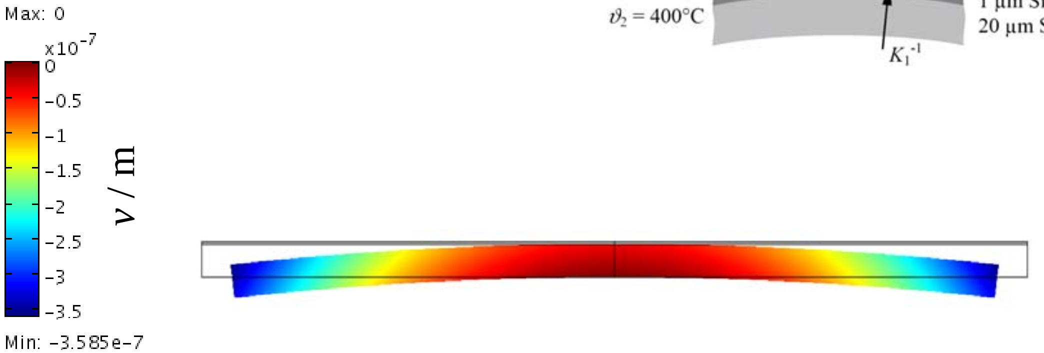
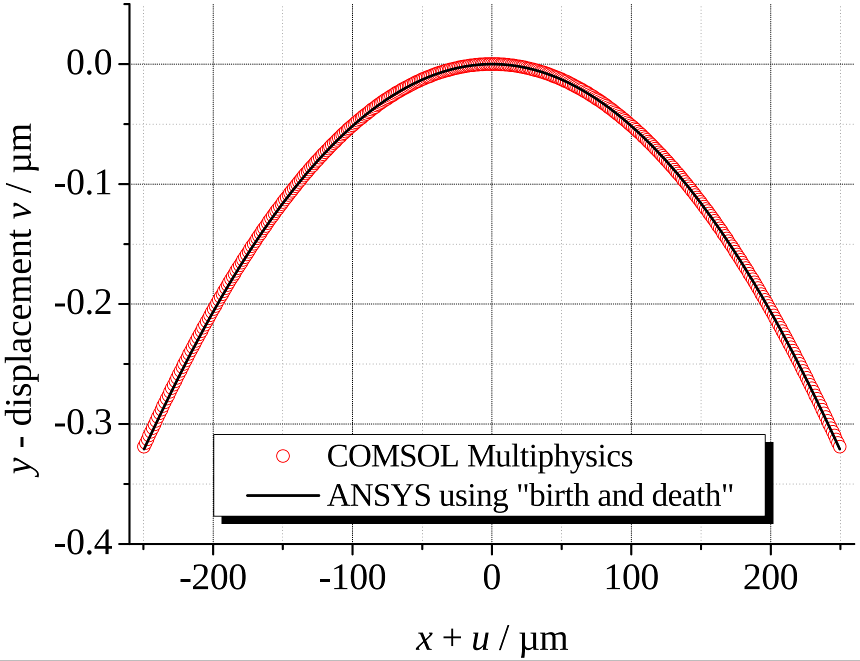
Results

y – displacement:

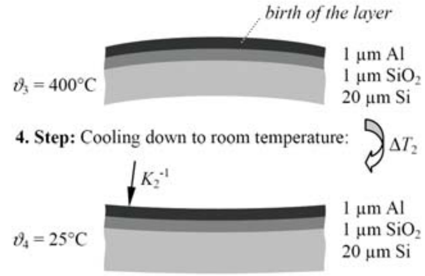
After thermal oxidation at $\vartheta = 400°C$:

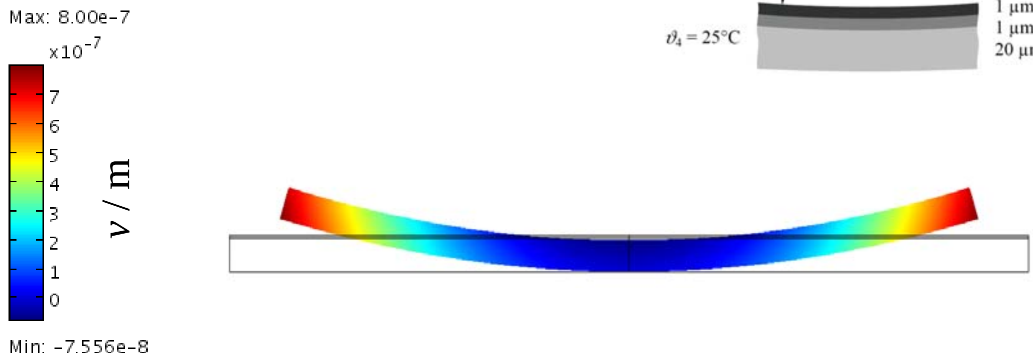


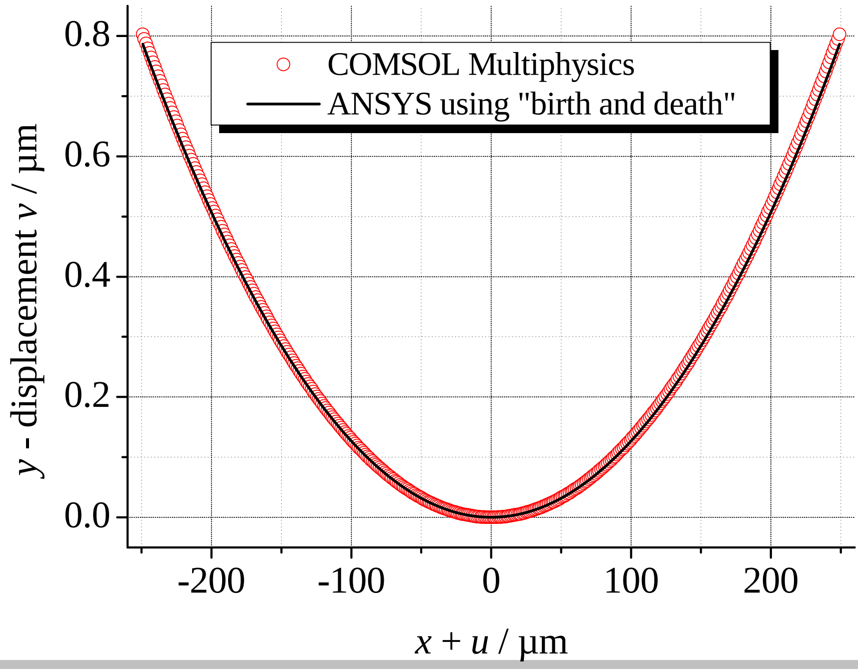




After aluminium deposition at $\vartheta = 25°C$:







40 x scaled surface deformation!

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Results

- Comparison with the reference FEA:

Method after deposition of:	curvature K / m^{-1} layer 2	 layer 3	relative deviation / % layer 2	 layer 3
COMSOL with "birth and death":				
linear	-10.23	25.78	-0.9	1.7
large deformation	-10.25	**25.87**	-0.7	**2.1**
COMSOL without "birth and death":				
linear	-	15.32	-	-39.6
large deformation	-	15.37	-	-39.4
ANSYS with "birth and death": (Reference)				
large deformation	-10.32	**25.34**	0.0	**0.0**
ANSYS without "birth and death":				
large deformation	-	14.95	-	-41.0

- → more accuracy with *birth and death*

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Summary and Outlook

- *Birth and Death* is possible within COMSOL
- Main idea for *birth and death*:
  - Changing the YOUNG's Modulus
  - multiple application mode or stepwise solving
  - stress / strain coupling

- *Birth and Death* is useful for:
  - Simulation of multilayered coatings
  - Simulation of sacrificial layers
  - … Stress engineering in microsystem technology

- Further wants:
  - multilayered shells or solid-shells

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Thank You!

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