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Modeling of Vibrating Atomic Force Microscope's Cantilever within Different Frames of Reference

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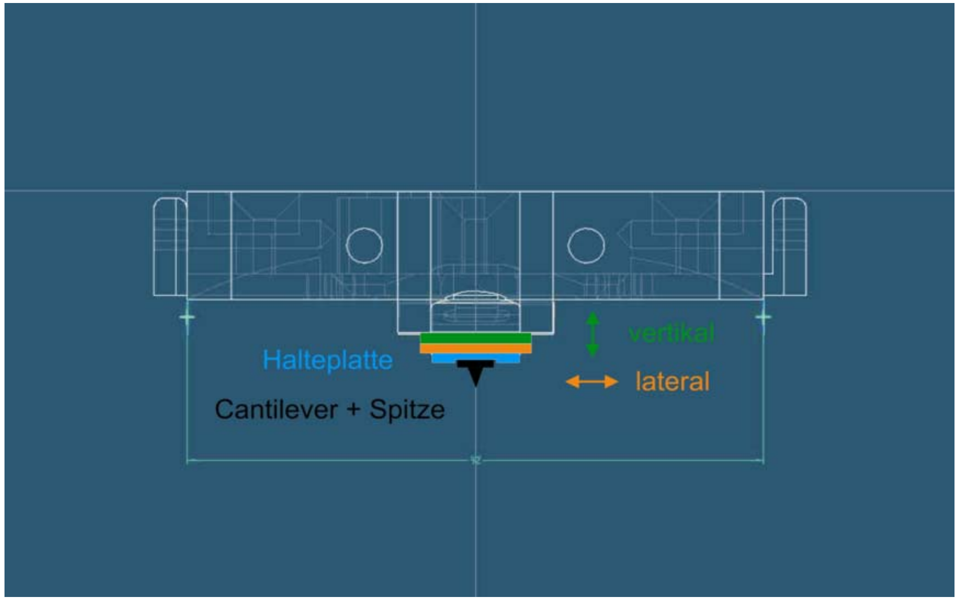
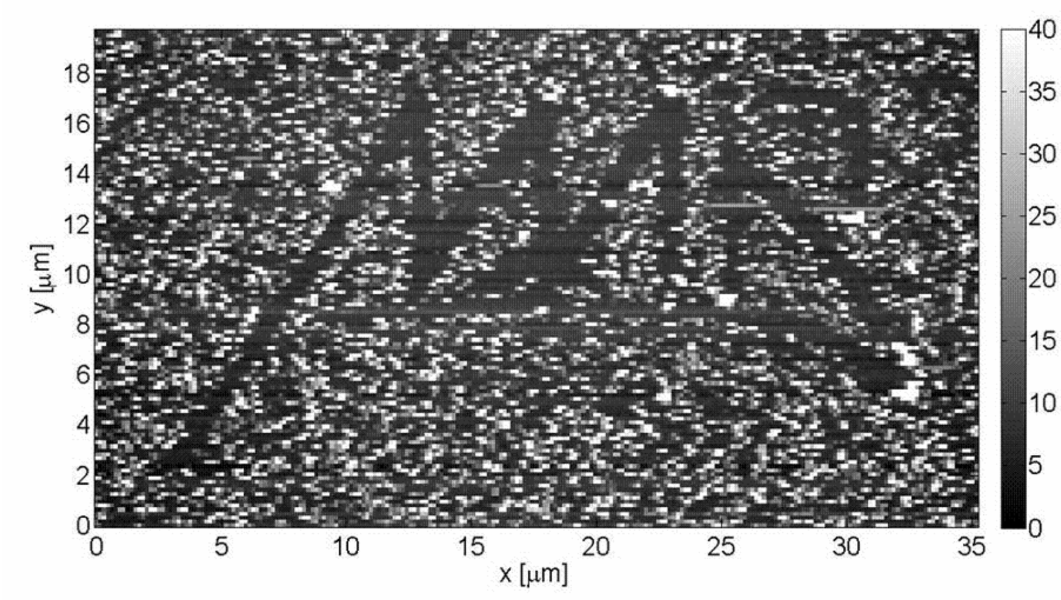
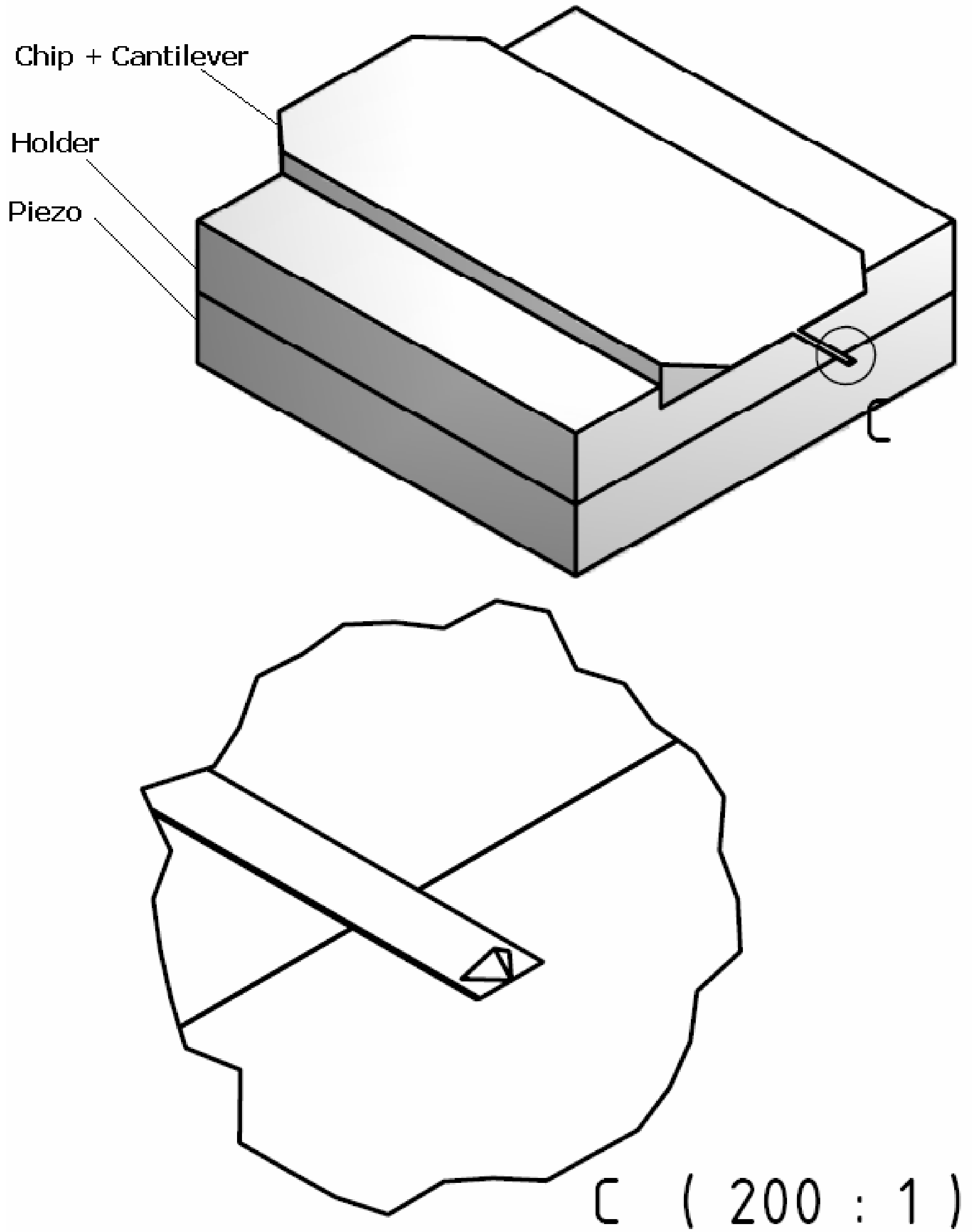


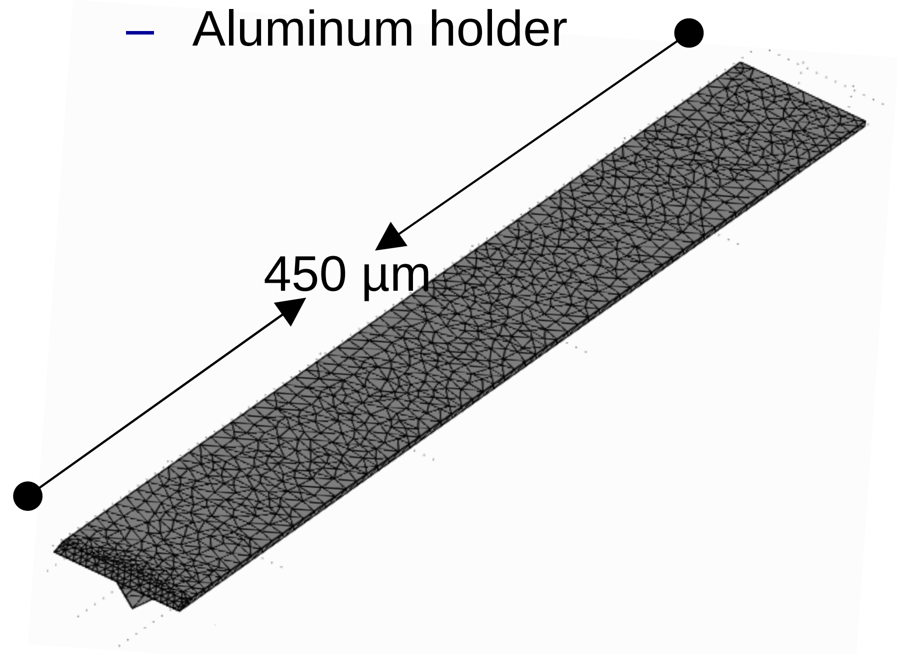


- **Objective**
  - Put up FEM based models for the simulation of cantilever vibration modes as tools for the on going work at the AFM – group in AMiR
  - Assess the feasibility of simulating cantilever beams in accelerated frames of reference
- **Field of research of this group includes among others:**
  - Manipulation by Lateral Cantilever Vibrations and Oscillations for AFM based nanohandling
  - Automation of AFM based nanomanipulation

Assembled Geometry Objects



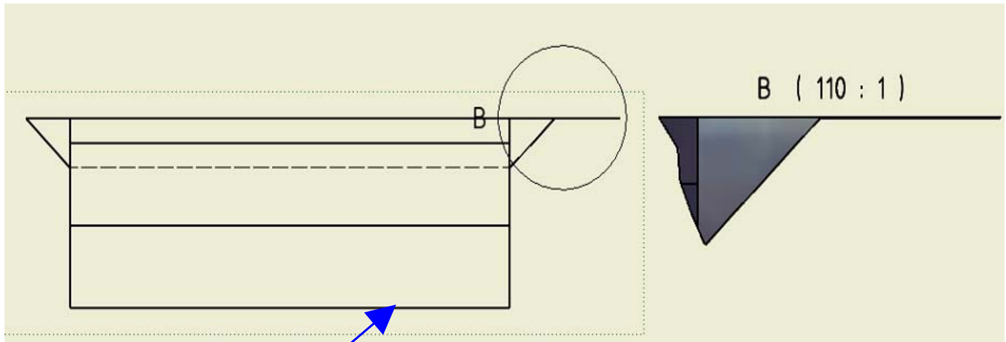
- Components were designed using Autodesk Inventor and imported into the COMSOL environment using the *CAD import tool*.
- Details of various components:
  - Cantilever: Single crystalline silicon (450 µm X 50µm X 2µm).
  - Piezo plate: Material PIC155
  - Aluminum holder



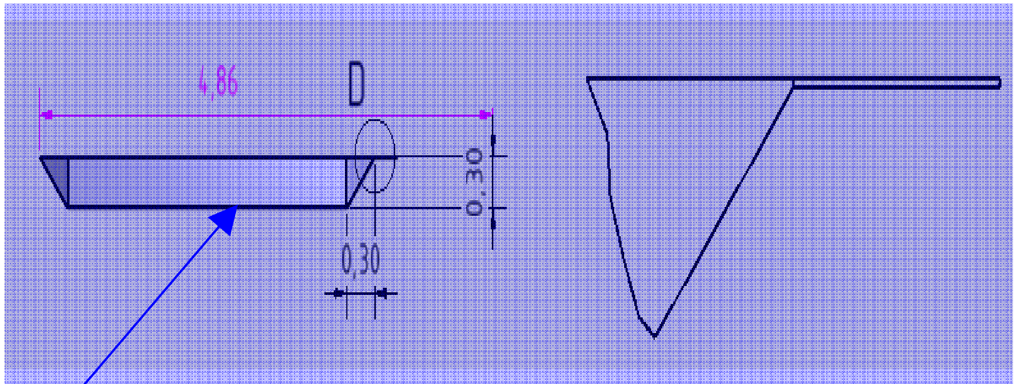
a. *Inertial Frame* Model

- Components: The chip, cantilever, holder and the piezo plate
- Excitation with 0.5 V across the piezo plate; frequency f = 13600 Hz
- Two mechanical and one electrical boundary conditions.
- Multiphysics model: *stress-strain* and the *piezo domain* from the MEMS module.

a).



b).



Points at rest

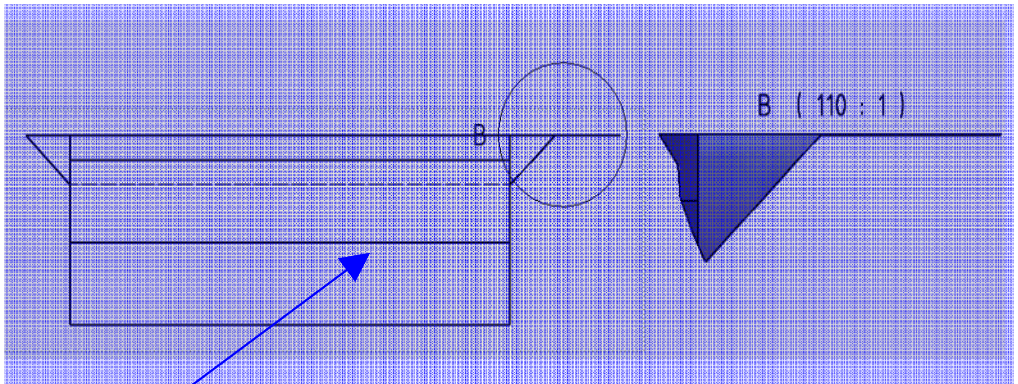
Points at rest

b. *Accelerated Frame* Model

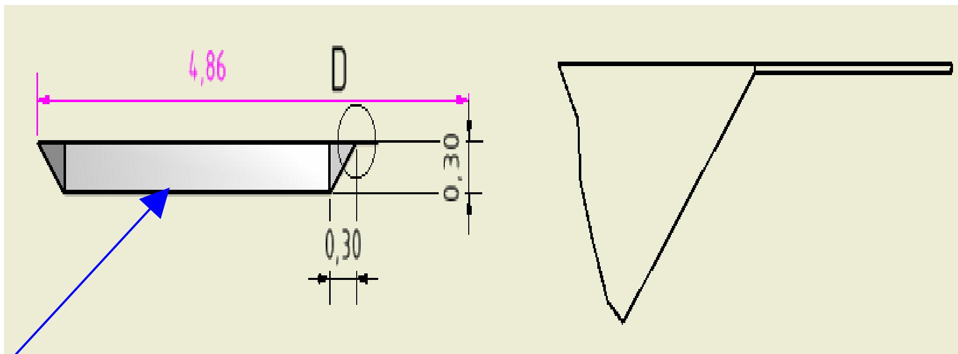
- Aims at simplification of the simulation process.
- Components: The chip and the cantilever beam
- Multiphysics model: Only *stress-strain domain*
- Frequency response - implemented in MatLab.
- One mechanical boundary condition.
- Sought Variables:
  - displacements ***u*****,** ***v*** and ***w***
  - from the normal stress (***ε***) and strain (***γ***)

$$\begin{Bmatrix} \epsilon_x \\ \epsilon_y \\ \epsilon_z \\ \gamma_{xy} \\ \gamma_{yz} \\ \gamma_{zx} \end{Bmatrix} = \begin{bmatrix} \frac{\partial}{\partial x} & 0 & 0 \\ 0 & \frac{\partial}{\partial y} & 0 \\ 0 & 0 & \frac{\partial}{\partial z} \\ \frac{\partial}{\partial y} & \frac{\partial}{\partial x} & 0 \\ 0 & \frac{\partial}{\partial z} & \frac{\partial}{\partial y} \\ \frac{\partial}{\partial z} & 0 & \frac{\partial}{\partial x} \end{bmatrix} \begin{Bmatrix} u \\ v \\ w \end{Bmatrix}$$

a).



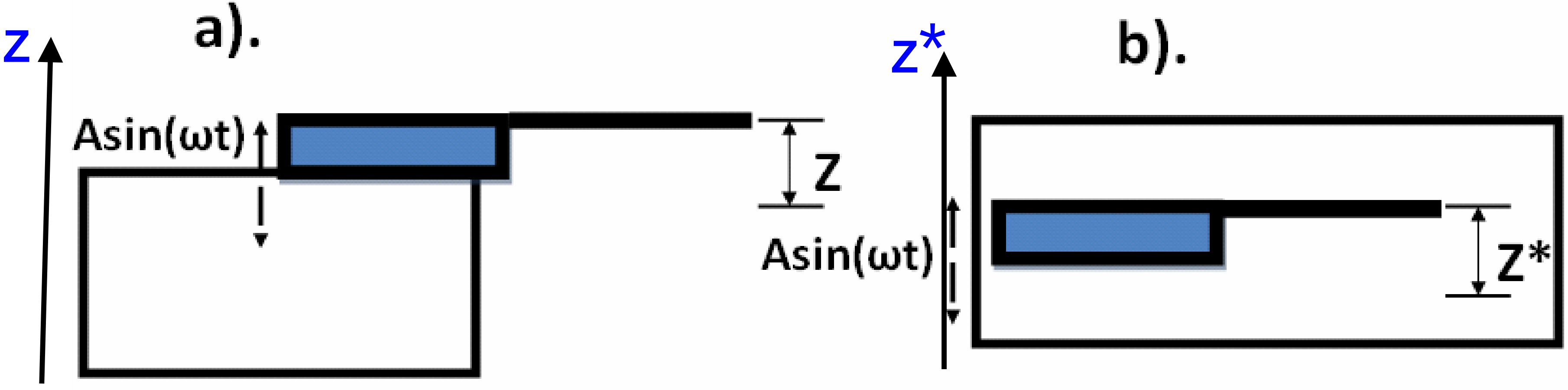
b).



Points at rest

Points at rest

Setting up the Models



Relationship between Vertical Coordinates (z,z*):

$$z = z^* + Asin(\omega t)$$

Newton's Second Law:

$$m\ddot{z} = m\ddot{z}^* - mA\omega^2 \sin(\omega t)$$

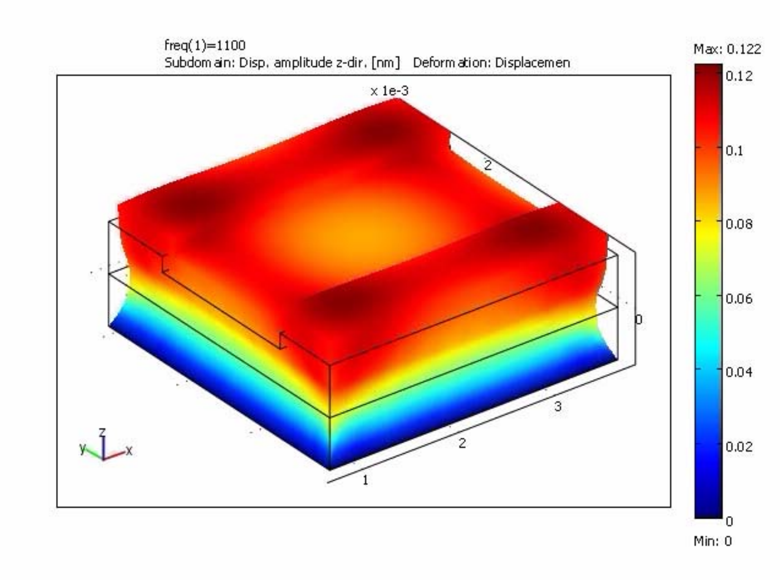
Fictitious Force:

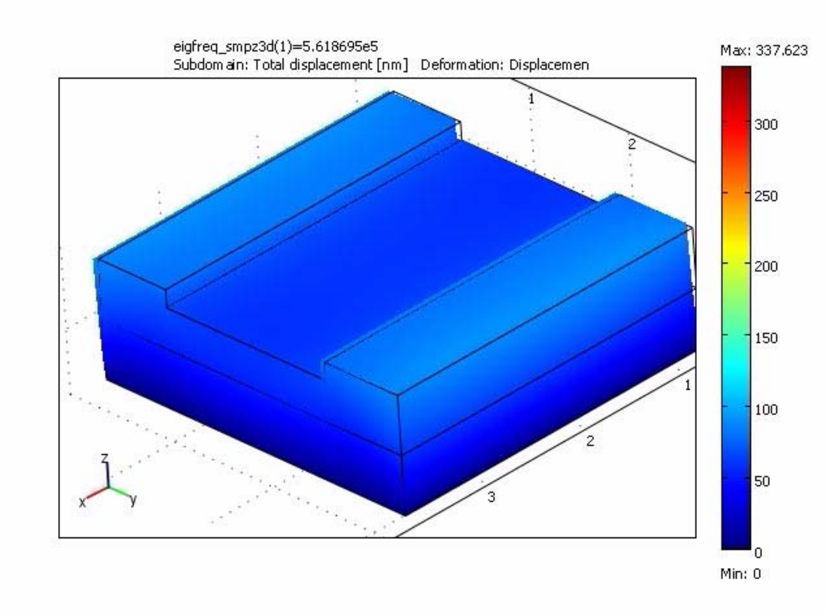
$$F_z^* := F_z + mA^2 \sin(\omega t) = m\ddot{z}^*$$

Fictitious Load:

$$L_f := \rho A\omega^2 \sin(\omega t)\,; \qquad \rho := m/V$$

Vibration Amplitude

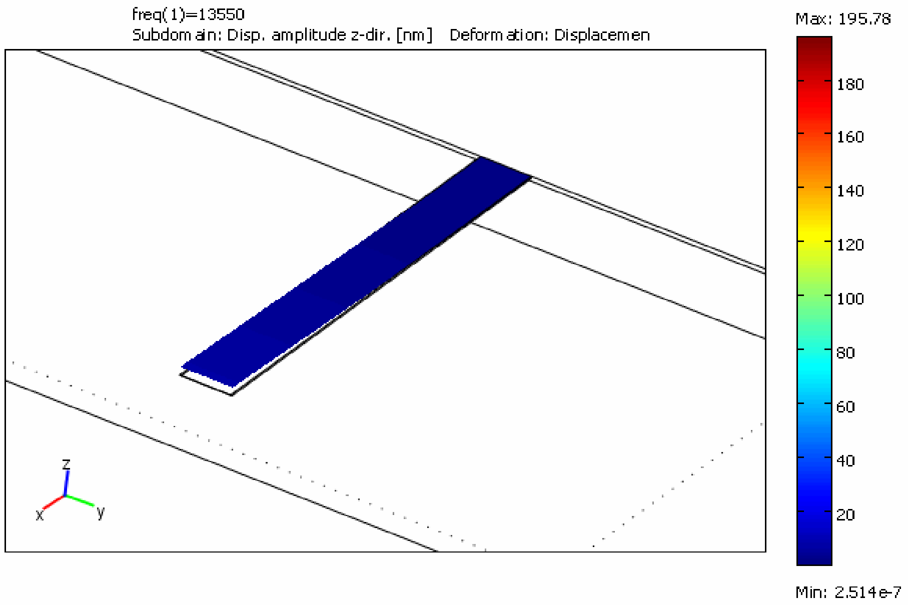


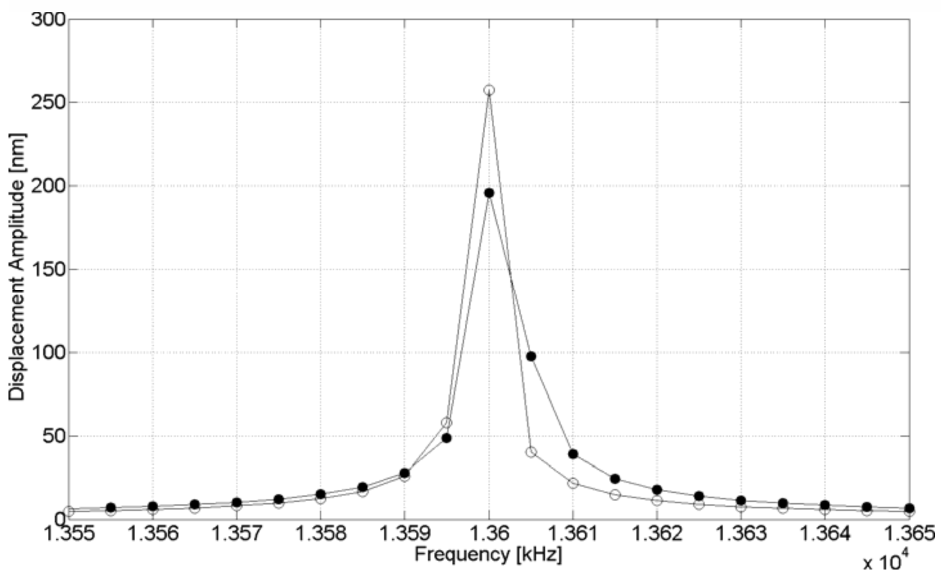


Simulation of the actuation system:

- **Frequency Response**
  - Determine the vibration amplitude of the piezo plate at the holder (Frequency = 13600 Hz and Voltage = 0.5 V): Result - (A_{sim} = 0.0430 nm)
  - Frequency dependent
- **Eigenfrequency Response**
  - The 1st 20 eigenfrequencies of the piezo plate and holder (between $5.62 \times 10^5 – 1.12 \times 10^6$ Hz), hence no influence on the cantilever.
  - For every eigenfrequency max displacement is shown

Results from both models





- Displacement amplitude at the tip of the cantilever. Resonance peak at the frequency:

  $f_{Mod1} = f_{Mod2} = (13.600 \pm 0.005)$ kHz

- This corresponds well with the analytically determined frequency for a clamped-free cantilever beam

  $f_{theo} = 13.586$ kHz

  and the frequency specification range stated by the manufacturer

  $f_{Manu} = 13 \pm 4$ kHz

- Simulation time for both models (CPU time):

  $T_{Mod1} = 3.375 * T_{Mod2}$

Conclusion

Discussion

- Simulation of cantilever‘s vibration modes, when implemented in suitably chosen frames of reference can:
  - Help reduce computational burden
  - Shorten calculation time
- Results for the resonance frequency agree within ***± 5 Hz.***
- Lack of damping leads to resonance catastrophe, thus no comparison amplitude possible in this case

Outlook

- Implementation of damping
- Comparison of amplitude values with experimental results

Acknowledgements

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