Piezo-actuated Nanodiamond Cantilever Technology for High Speed Applications

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Cranfield UNIVERSITY

Filtronic

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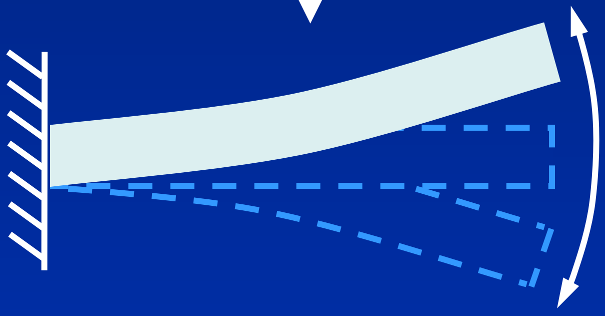
Motivation

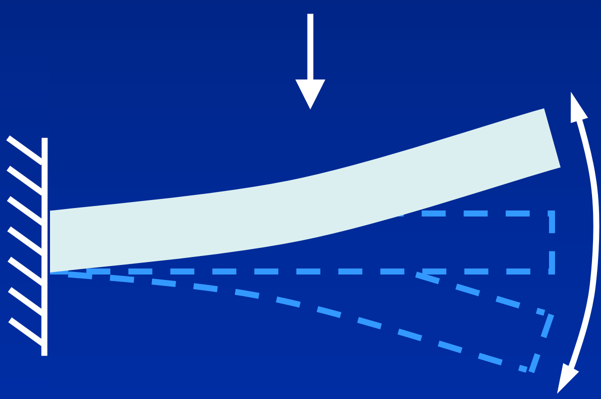
Cantilever actuator → Different actuation schemes

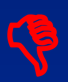


- electrostatic
- thermal
- (magnetic)
- piezoelectric

Motivation

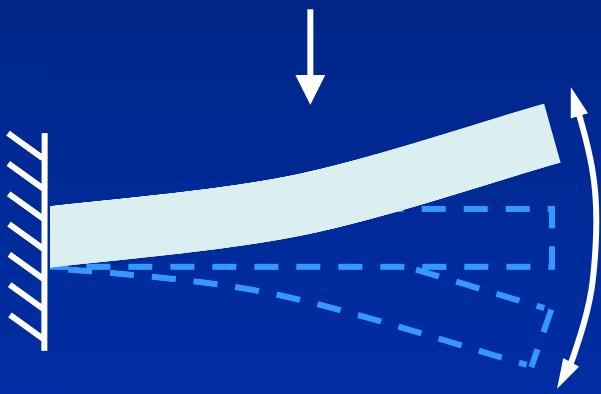
Cantilever actuator

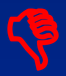
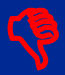


	electro-static	thermal	piezo-electric
actuation voltage			

Motivation

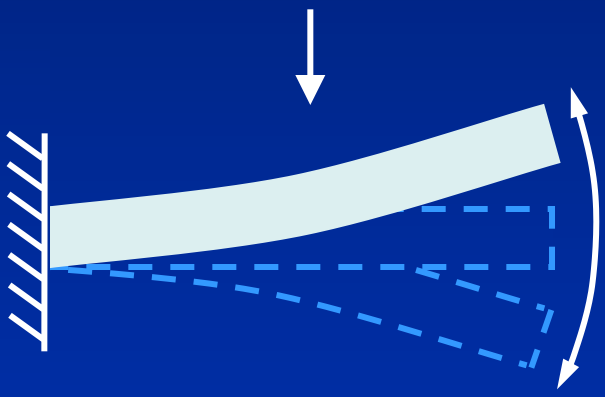
Cantilever actuator

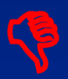
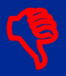


	electro-static	thermal	piezo-electric
actuation voltage			
stimulation speed			

Motivation

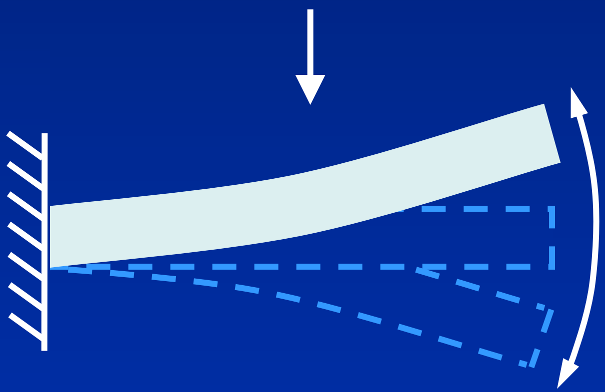
Cantilever actuator



	electro-static	thermal	piezo-electric
actuation voltage			
stimulation speed			
initial forces			

Motivation

Cantilever actuator



	electro-static	thermal	piezo-electric
actuation voltage	👎	👍	👍
stimulation speed	👍	👎	👍
initial forces	👎	👍	👍
electrical pullback	✗	✗	✓

Goal: MHz resonance MEMS Actuator

But why PZT-NCD couples?

- *PZT: Lead zirconate titanate*

  Deposition methods:

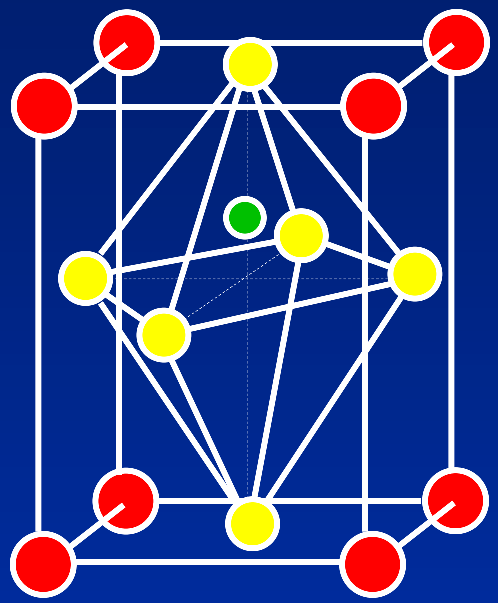
  - MOCVD (Auciello et al. ADC 2005)
  - Sol-gel (Kusterer et al. Diamond 2006)
    - 👍 low cost
    - 👍 lower thermal budget
  - 👎 Problem: adhesion

- *NCD* good carrier for brittle PZT because of high mechanical stability
  - 👍 high reset force (dominated by stiffness)
    - ☞ fast switch-off
  - 👍 high resonance frequency
    - ☞ high frequency of operation

Outline

- Piezo-effect in Unimorphs
- Fabrication Steps
- Results
- Conclusions

Piezo-effect in PZT



Piezo-material:

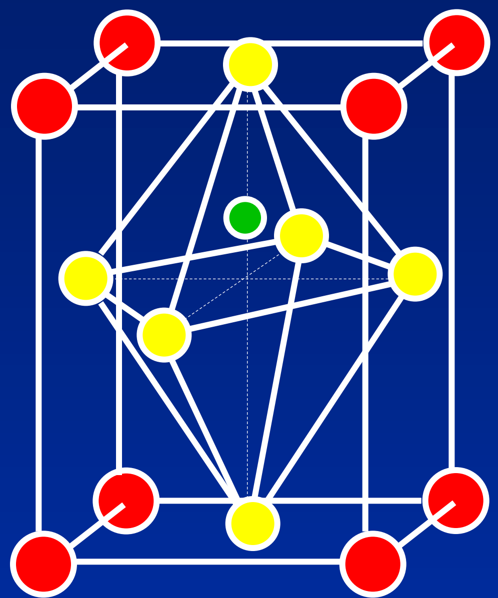
Lead Zirconate Titanate (PZT)

← Tetragonal lattice

☞ *perovskite* structure

- Lead (Pb^{2+})
- Oxygen (O^{2-})
- Titanium or Zirconium (Ti^{4+}, Zr^{4+})

Piezo-effect in PZT



Lead (Pb^{2+})

Oxygen (O^{2-})

Titanium or Zirconium (Ti^{4+}, Zr^{4+})

<u>Piezo-material:</u>

Lead Zirconate Titanate (PZT)

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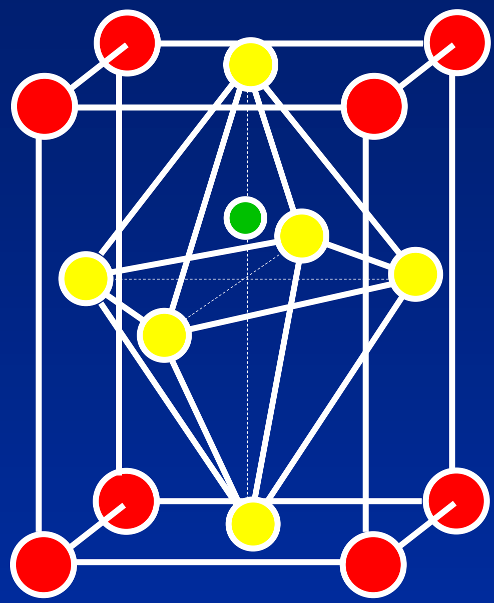
👍 ferroelectric ☞ can be poled after deposition

Piezo-effect in PZT



- Lead (Pb^{2+})
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Piezo-material:

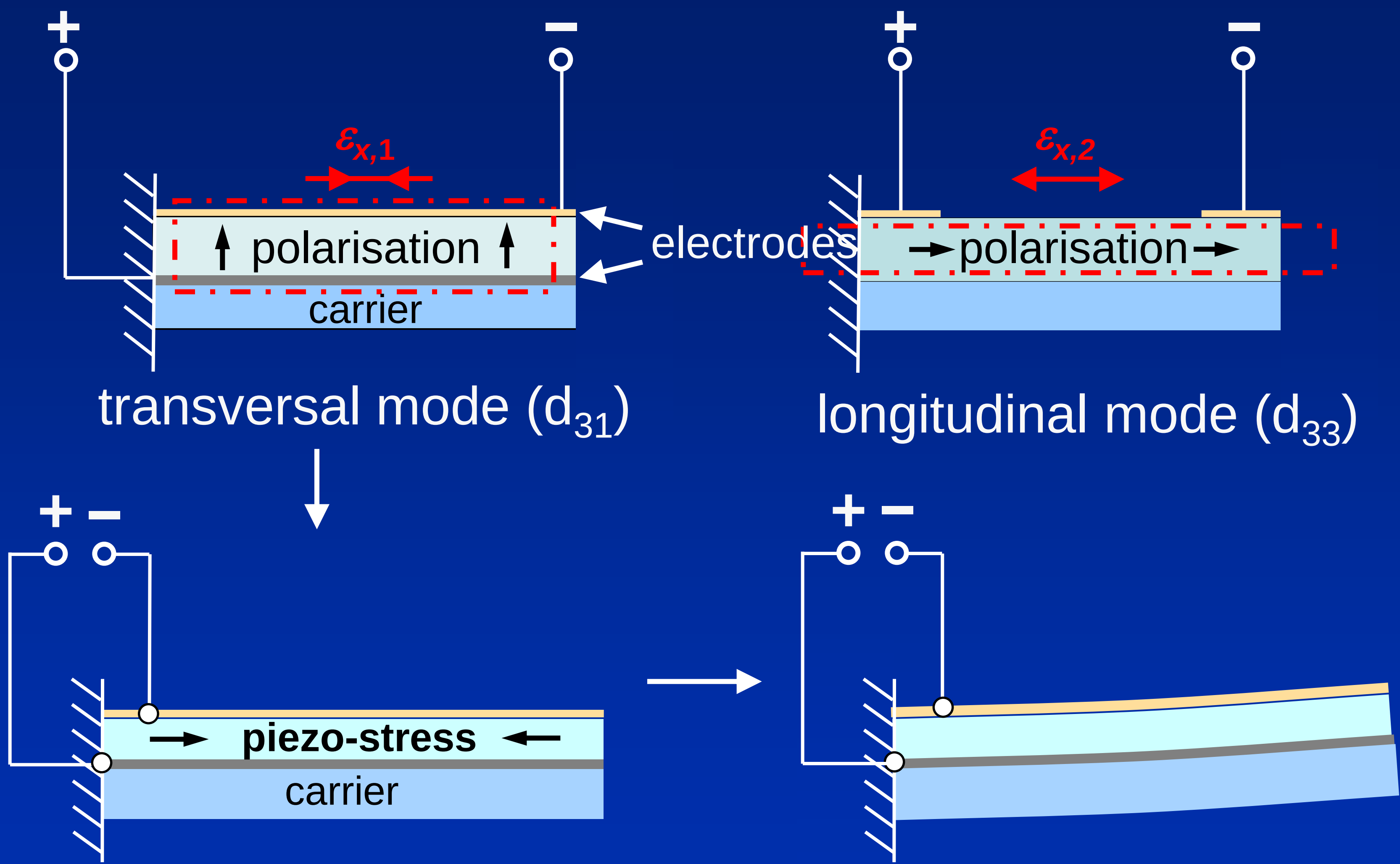
Lead Zirconate Titanate (PZT)

← Tetragonal lattice

☞ *perovskite* structure

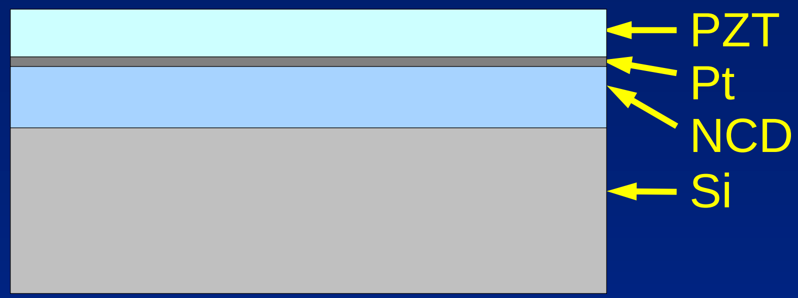
- 👍 ferroelectric ☞ can be poled after deposition
- 👍 large piezo-coefficients (d_{31} > 200 pm/V)

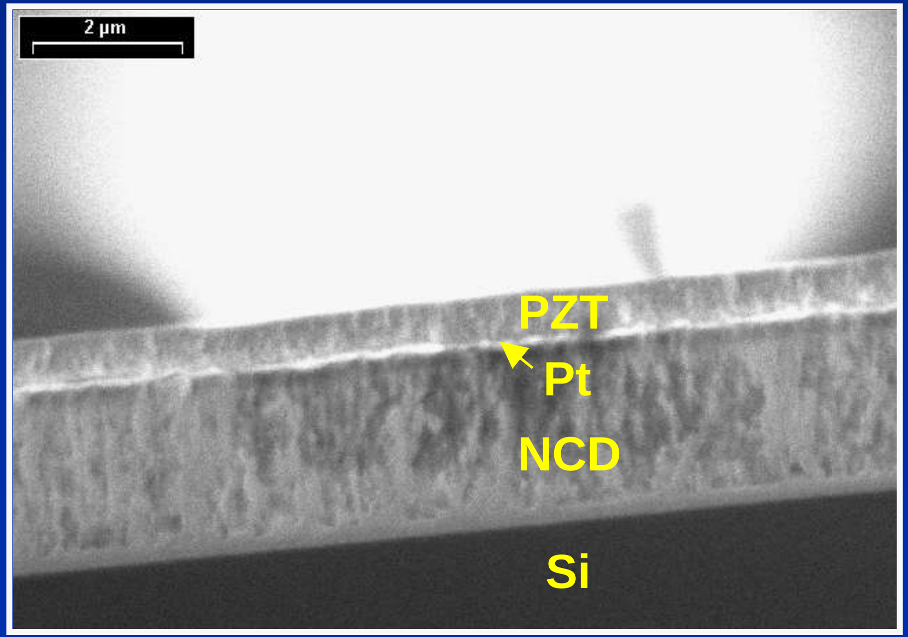
Piezo-actuated Unimorph Structure



cantilever bending

Previous Results - Substrate Preparation



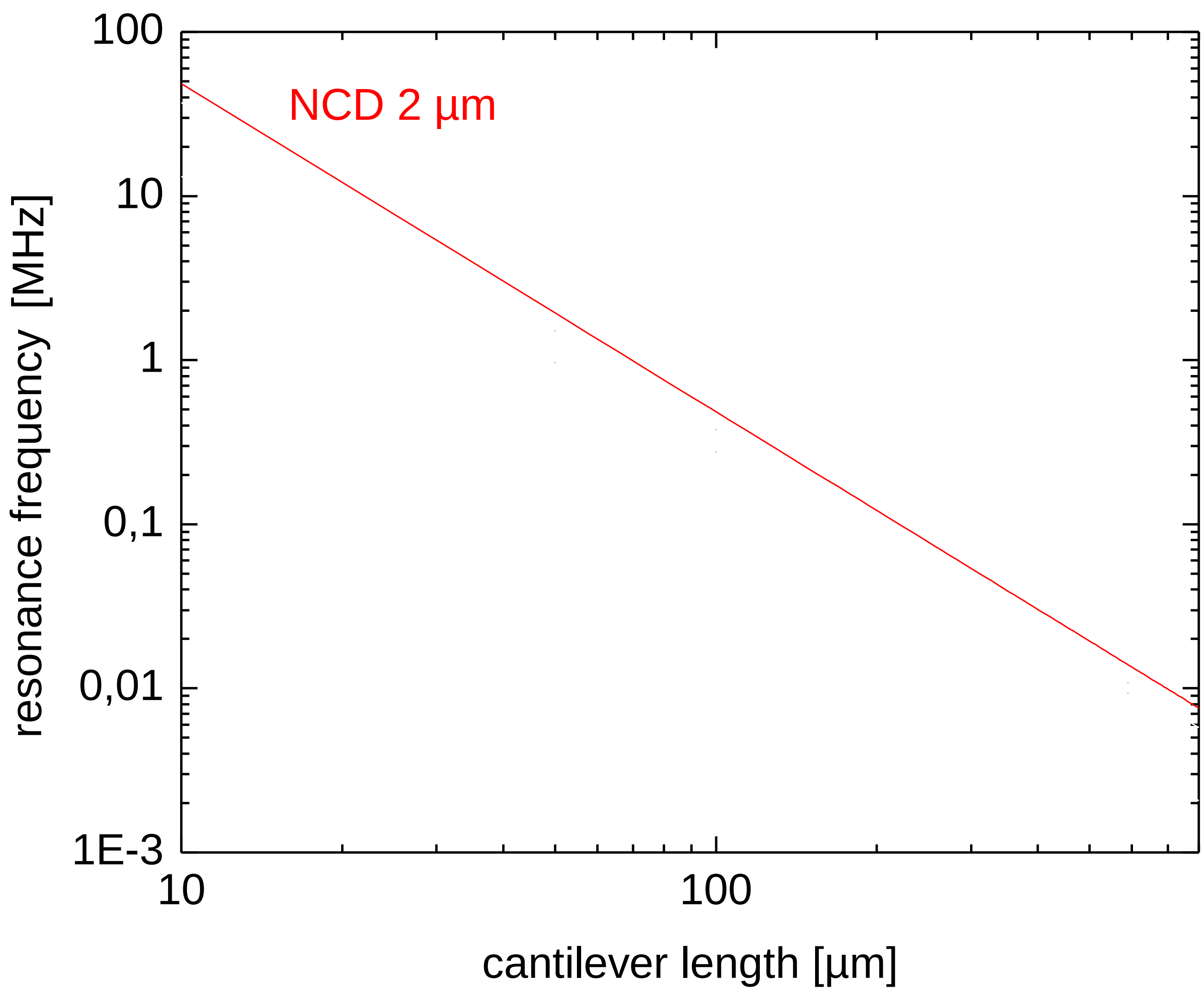


Deposition of PZT by sol-gel spinning onto NCD using Pt nucleation layer

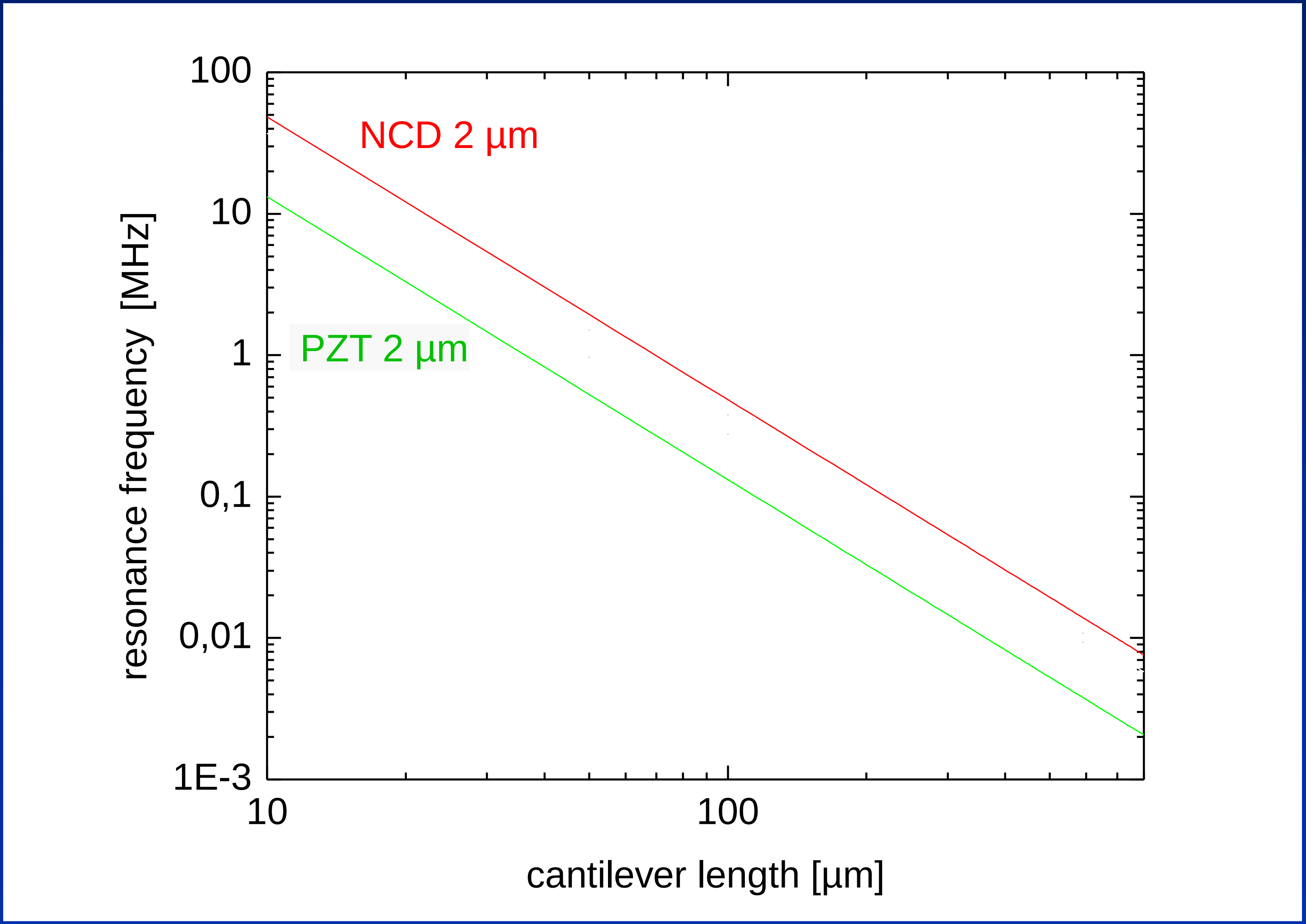
PVD Pt (200) textured solidifcation

Cross section view of *PZT on NCD* (Diamond 2006)

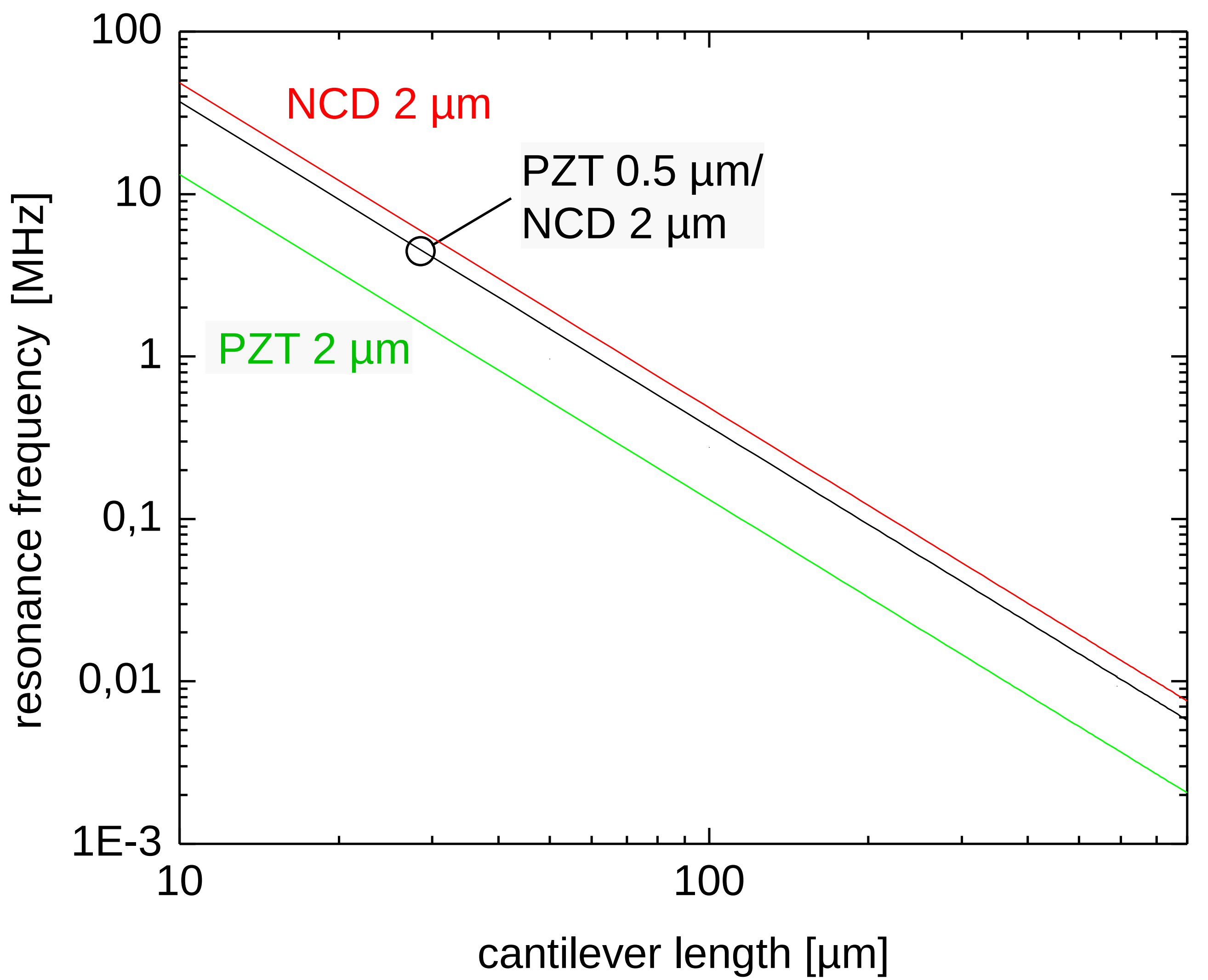
Expected Resonance Frequency



Expected Resonance Frequency

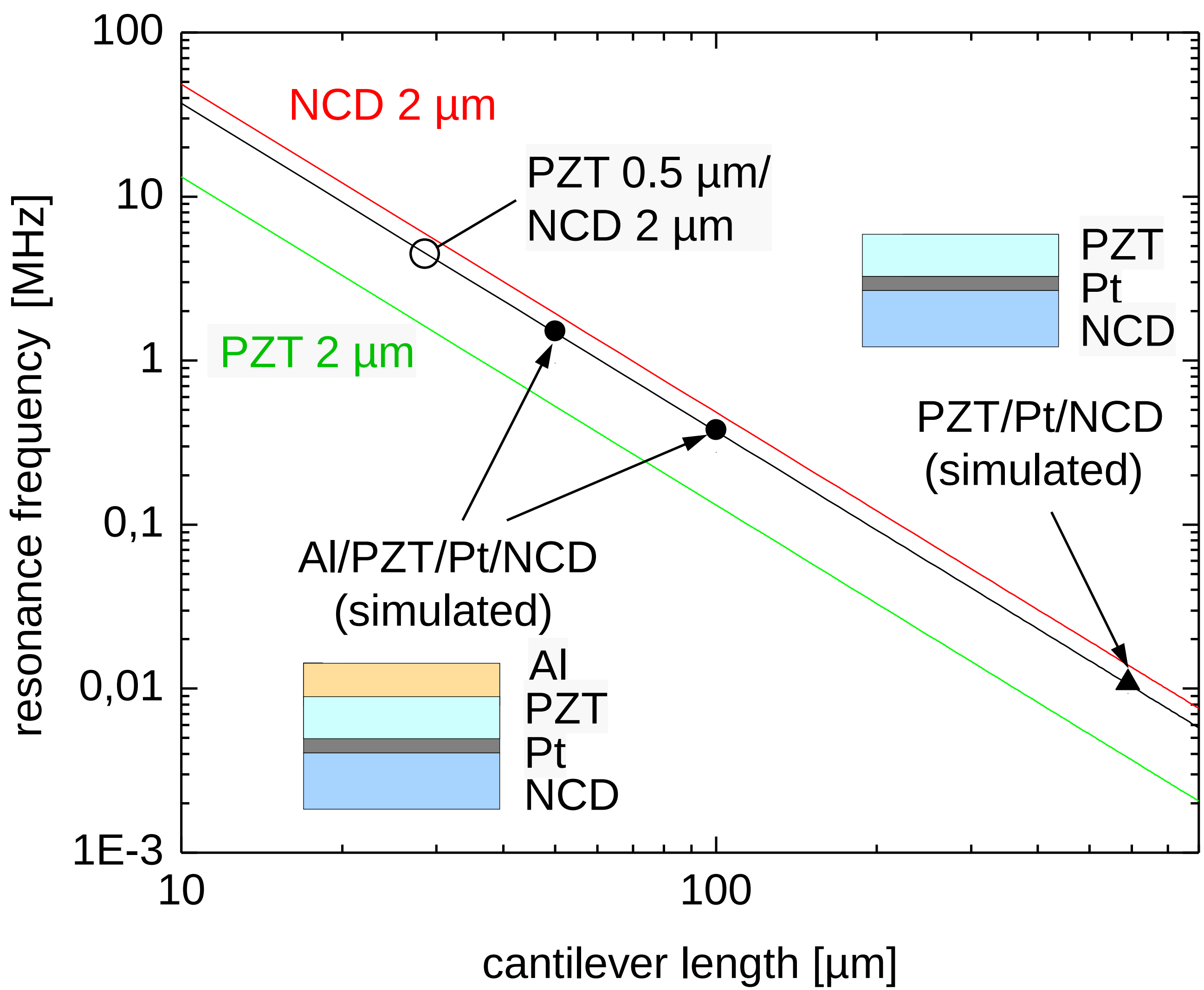


Expected Resonance Frequency

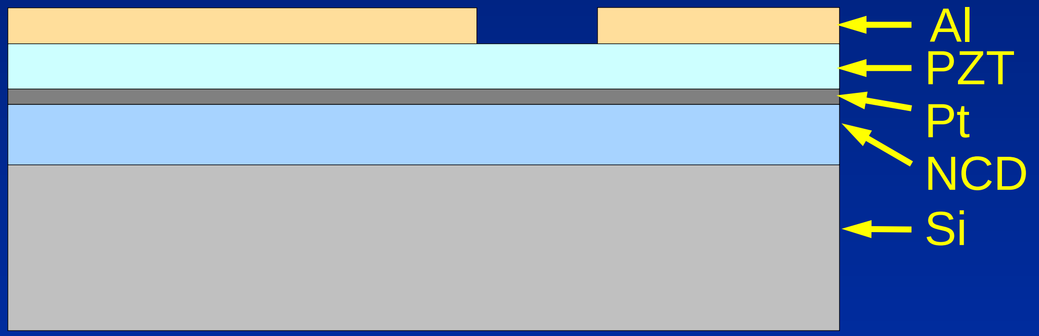


Expected Resonance Frequency

University of Ulm

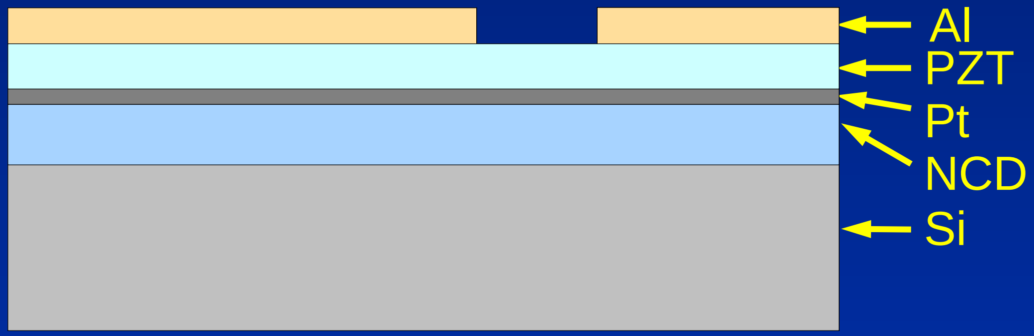


Fabrication Steps



Deposition of metal hard mask

Fabrication Steps

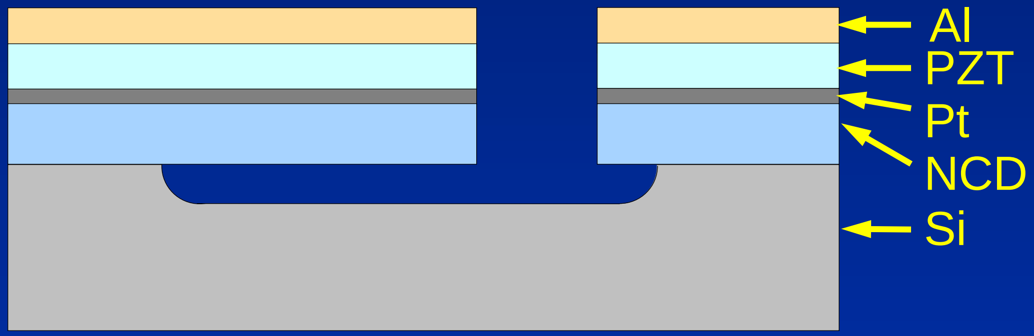


Dry etching of PZT, Pt, and diamond

⇨ **Self-aligned etching process**

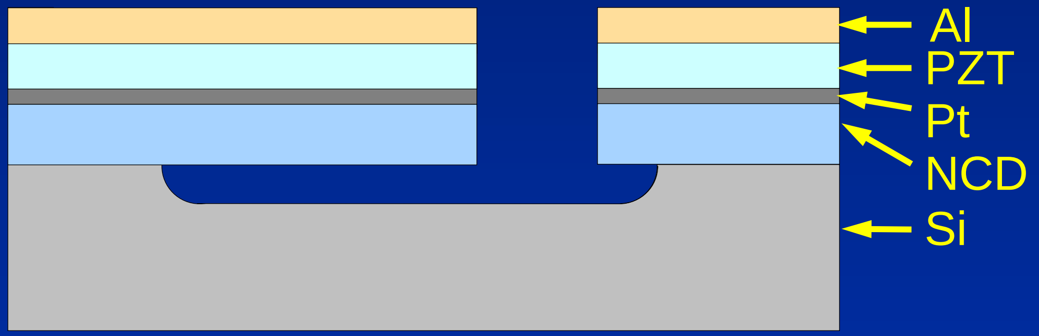
Fabrication Steps

University of Ulm



Cantilever release by dry etching

Fabrication Steps



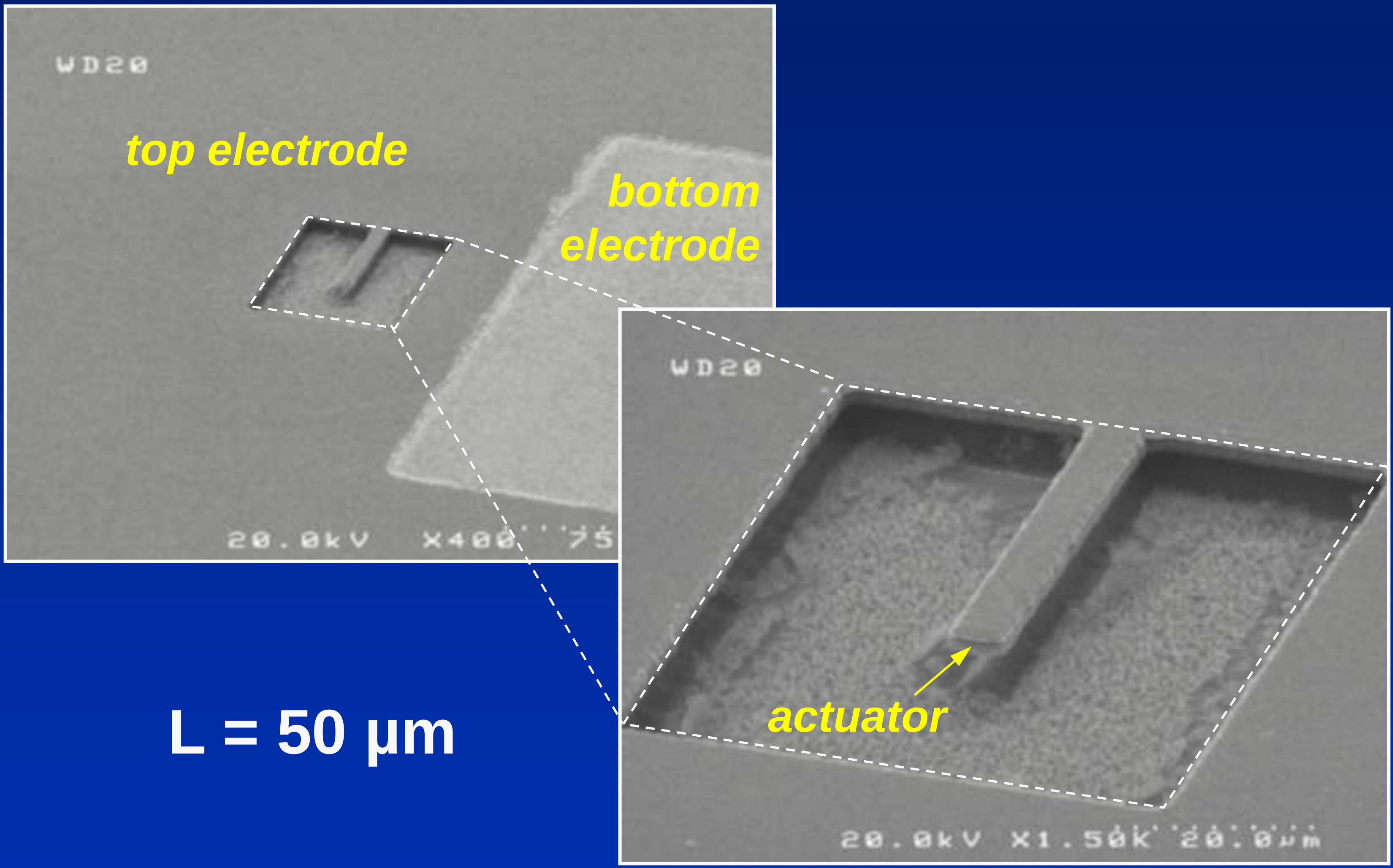
Wet chemical opening of bottom electrode

Fabrication Steps

Benefits of technology:

- large area deposition of NCD and PZT
- very few fabrication steps
- ***self-aligned process***

Fabricated Devices

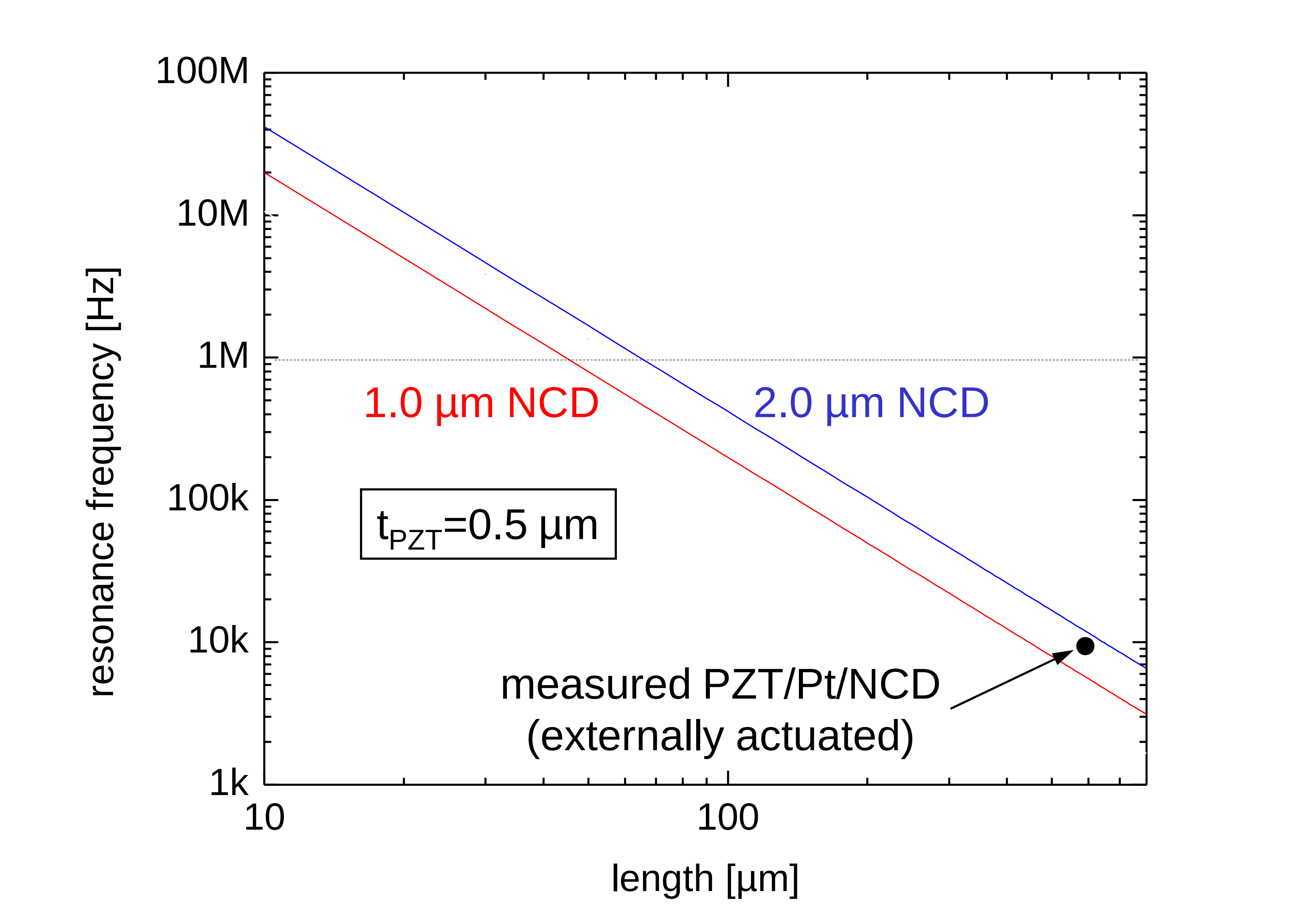


L = 50 µm

Operation at Resonance Frequency

Resonance of 50 µm cantilever @ 1.35 MHz

Measured Resonance Frequencies



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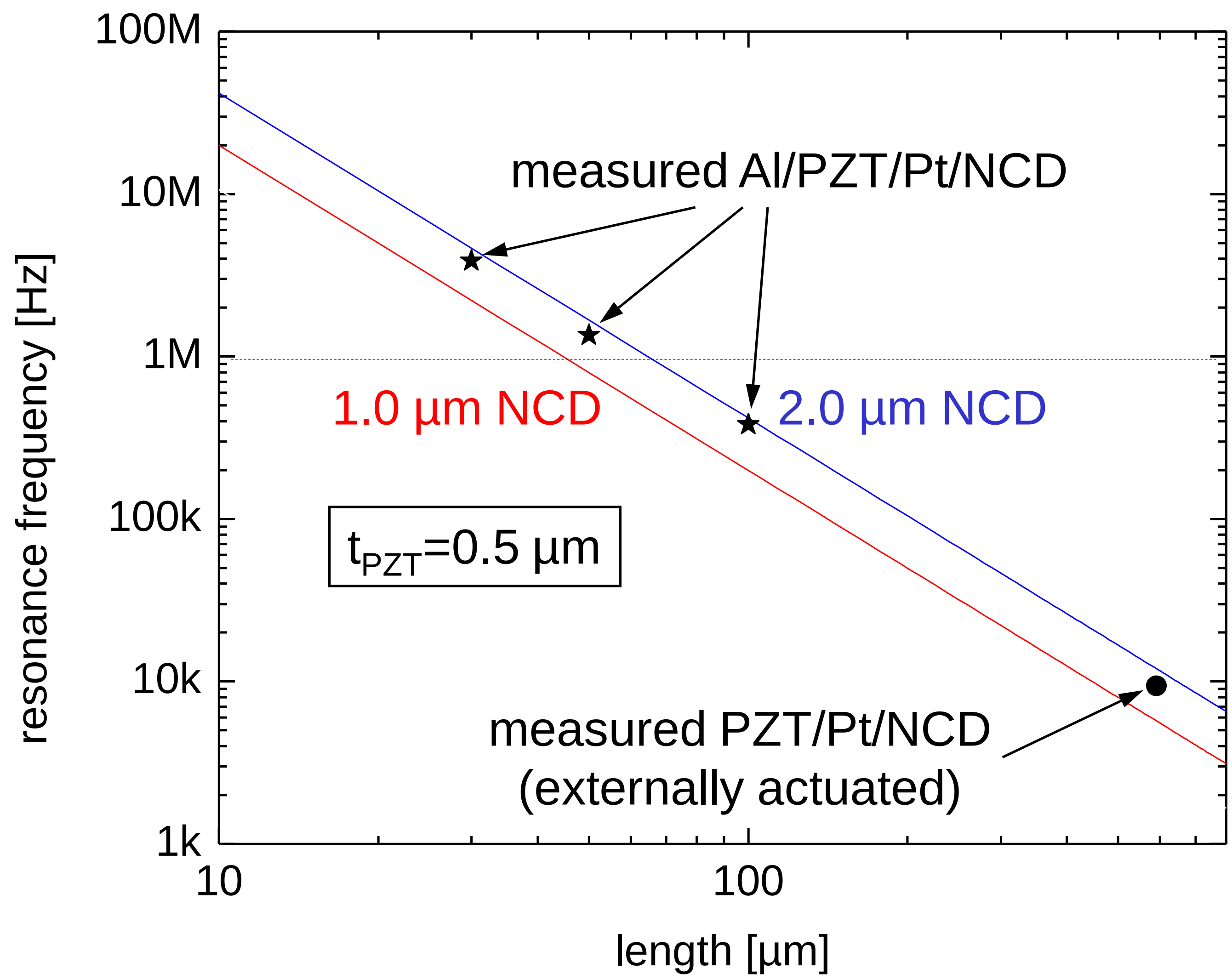

Conclusions

- Process for sol-gel derived PZT deposition onto NCD developed
- High speed actuators successfully demonstrated
  - **Resonance frequency in the MHz range**
- Applications: fast MEMS switches, mechanical resonators, tunable capacitors
- low temperature deposition process

  solidification at ~ 500 °C