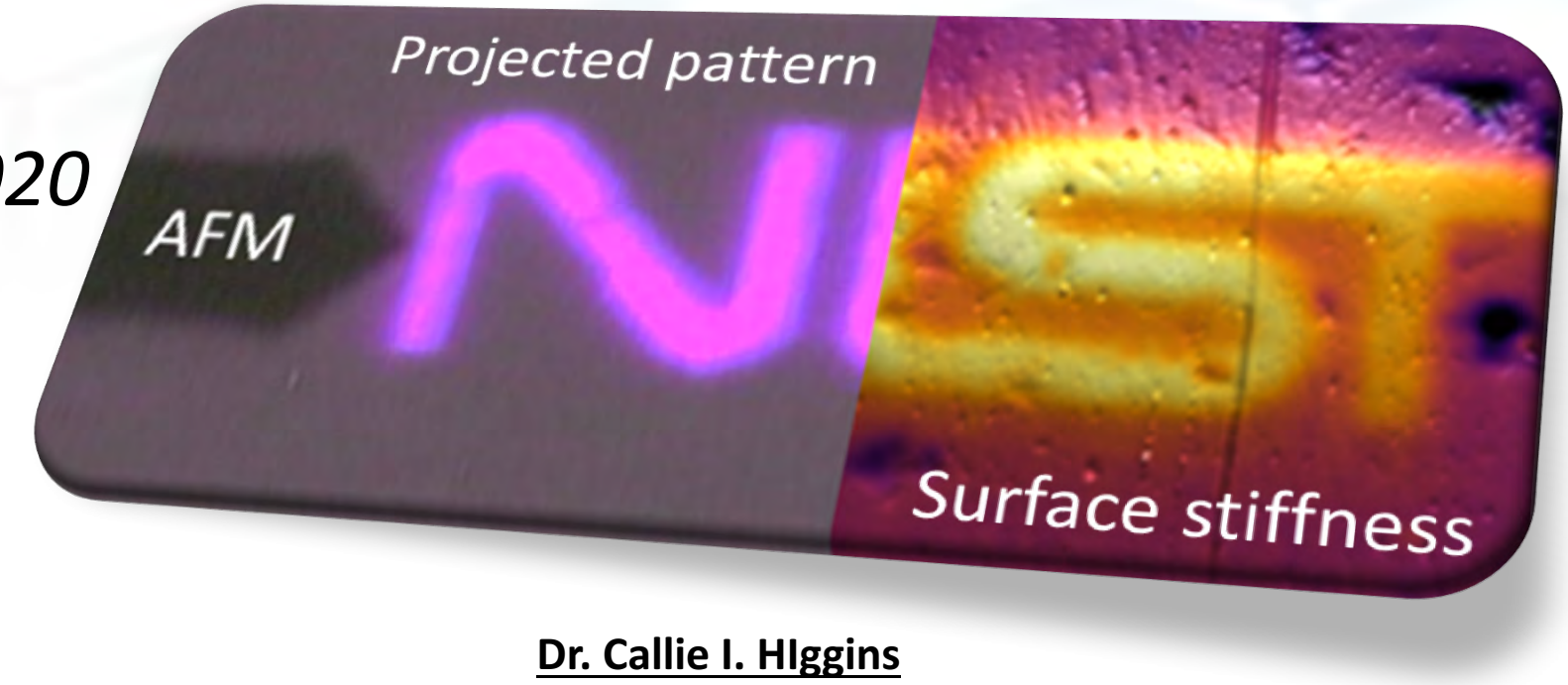
In Situ 3D Printed Voxel Correction Using Hybrid AFM 3D Printer

RadTech 2020
9 March 2020
Orlando, FL



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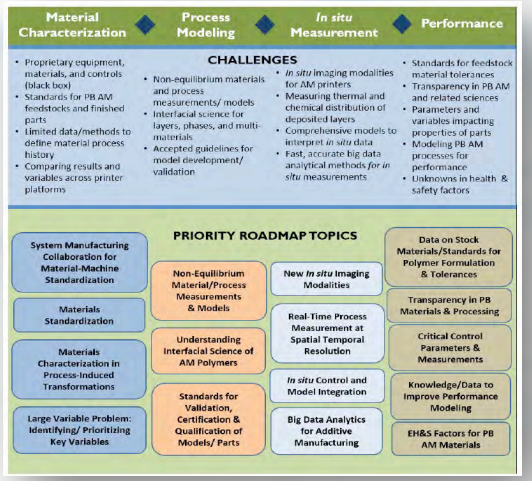
NIST Mission and goals in additive manufacturing

To promote U.S. innovation and industrial competitiveness by advancing measurement science, standards, and technology in ways that enhance economic security and improve our quality of life



measurement science

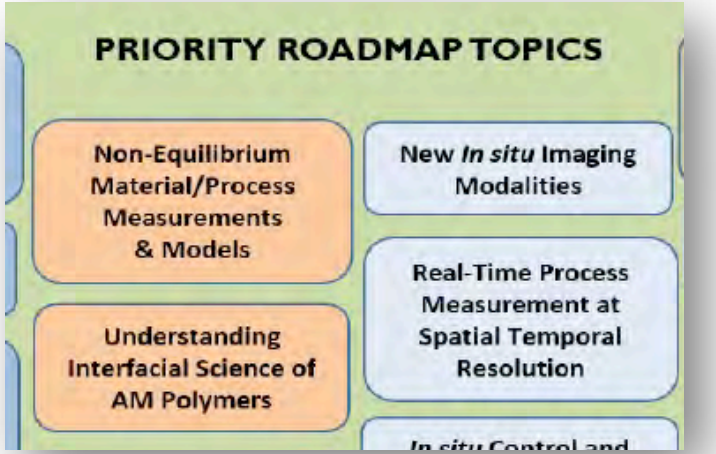
Creating the experimental and theoretical tools – methods, metrics, instruments, and data – that enable innovation

standards

Disseminating physical standards and providing technical expertise to documentary standards that enable comparison, ensure interoperability, and support commerce

technology

Driving innovation through knowledge dissemination and public-private partnerships that bridge the gap between discovery and the marketplace



PPAM Market Space

3D SYSTEMS

$1.2 B valuation

align

United Therapeutics CORPORATION

Carbon

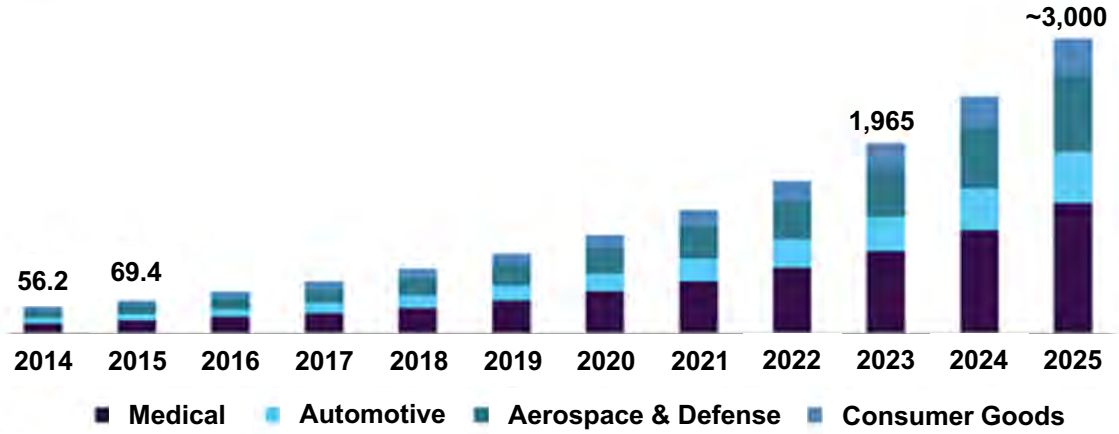
$2.4 B valuation

adidas, LAMBORGHINI, DENTCA CAD/CAM DENTURE, WILSON TOOL, Vitamix, Riddell, Ford, dyson, SONY, Google, Gillette, GE, TESLA

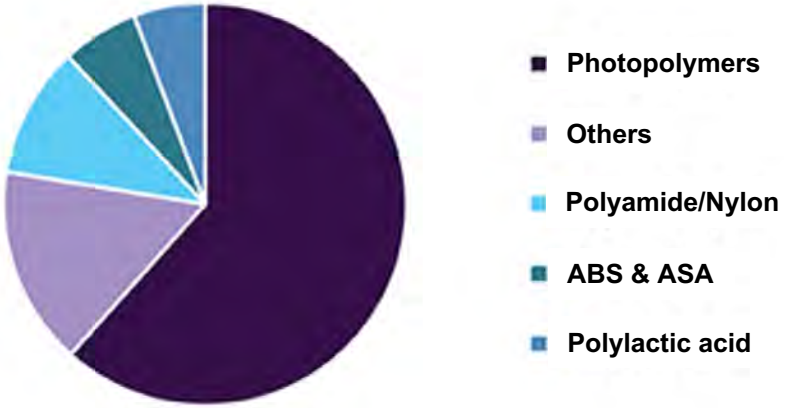
formlabs

$1 B valuation

U.S. 3D printing plastics market size, by application, 2014-2025, (USD Million)



Global 3D printing plastics market share, by type, 2017 (%)



https://www.grandviewresearch.com/industry-analysis/3d-printing-plastics-market

https://www.marketsandmarkets.com/Market-Reports/3d-printing-plastic-market-21707470.html

Our vision to realize potential of PPAM

To develop the technology to understand the fundamental properties of photopolymer AM materials both during and after printing to enable high throughout, high fidelity, and high performance PPAM with user-defined 3D control of the printed properties.

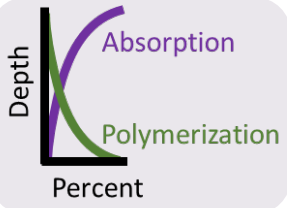
Print + resin environment

swelling behavior

diffusion of reactive species

print conditions *(intensity, exposure time, grayscale patterning, etc.)*

print heterogeneity



Resin

streamlined development

properties

(viscosity, reactivity, etc.)

Interface

adhesion

window materials *(FEP, AF, etc.)*

inhibition via dissolved gasses

heat generation/dissipation

Final print

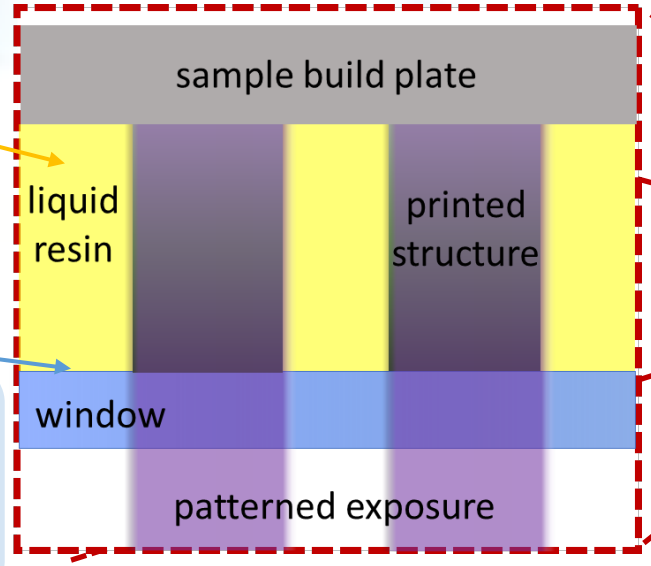
post processing

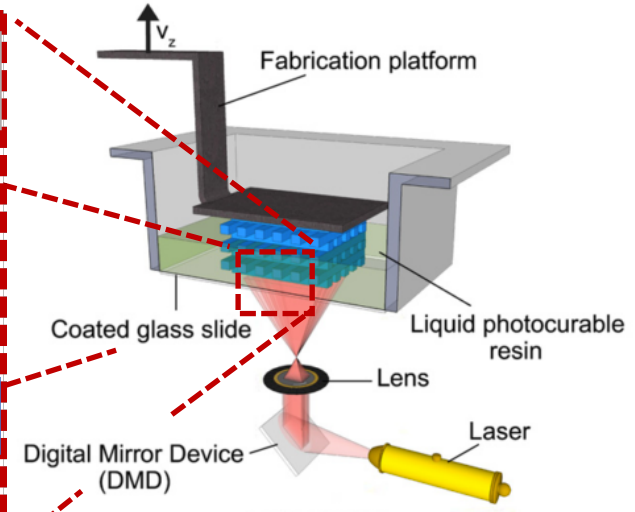
(washing, post cure, etc.)

final properties

(modulus, toughness, etc.)

fidelity and performance





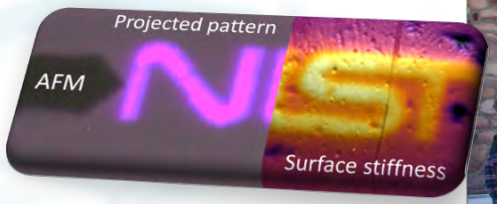
Our approach to achieve these goals:

- Novel instrumentation & characterization
- Standards development
- Strategic collaboration

Billiet, T. et al. *Biologically Responsive Biomaterials for Tissue Engineering (2013)*

Ouyang, Liliang, et al. Advanced Materials 29.8 (2017).

Our PPAM Vision



Polymer

- Boulder
- Photopolymer
- Stakeholder engagement

Consortium Development → Industry Collaborations → AM Bench → Roadmapping Workshop → Consortium Development

- Fundamental Science/Characterization tool development
  - Novel instrumentation & characterization
    - Hybrid AFM 3D printer-local, in situ voxel characterization
    - Nanomechanical rheological measurement
  - Standards development
    - Test structures to probe print processing condition and streamline resin characterization
    - Print calibration instrument (voxel rheometer)

Our PPAM Vision

Stakeholder engagement

Roadmapping report
- Distribute and talking point for upcoming conferences

Established NIST as pioneering leader in PPAM

Yearly meeting founded
- To be held on alternating years at NIST and at the RadTech annual conference (our co-organizer)

Roadmapping Workshop

AM Bench

Leading photopolymer AM bench initiative for 2021

Opportunity to drive PPAM standards development

Industry Collaborations

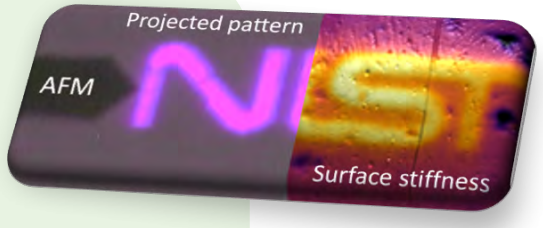
Tech transfer: Lumiode
- Use their LED array technology to build streamlined hybrid AFM Photopolymer AM system

3D Systems
- Develop characterization techniques with their senior scientist to streamline property and resin characterization

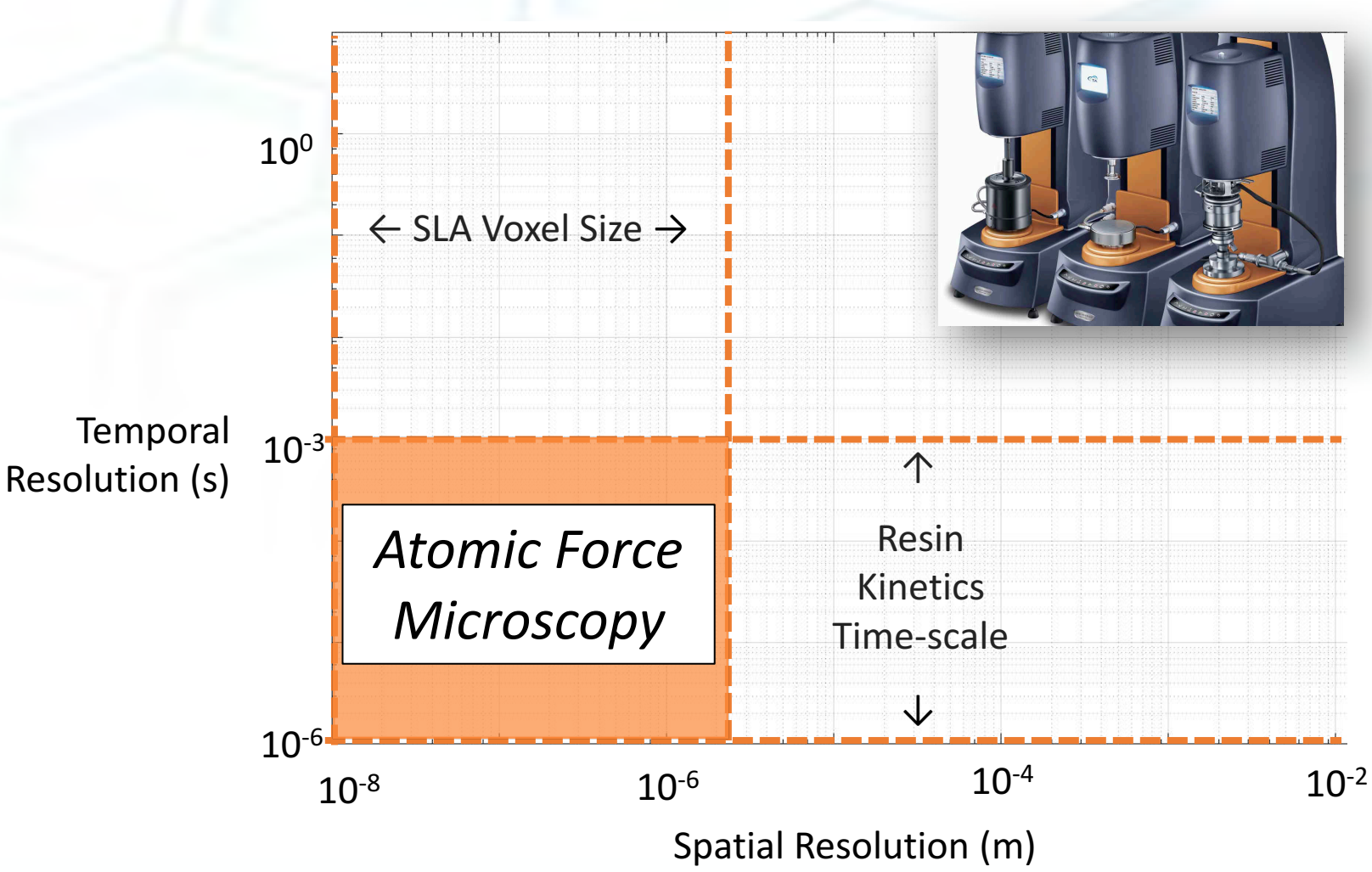
Consortium Development

Develop foundational characterization technology behind PPAM and avenue to grow PPAM team

Targeted (interested) members (~$50K dues):
- Printer OEMS: 3D Systems, Formlabs, Carbon, Azul 3D
- Resin suppliers: BASF, Sartomer, Henkel, DSM
- End Users: Ford, GE Additive, FastRadius, Uncountable, Align



Realizing the PPAM Vision: in situ characterization

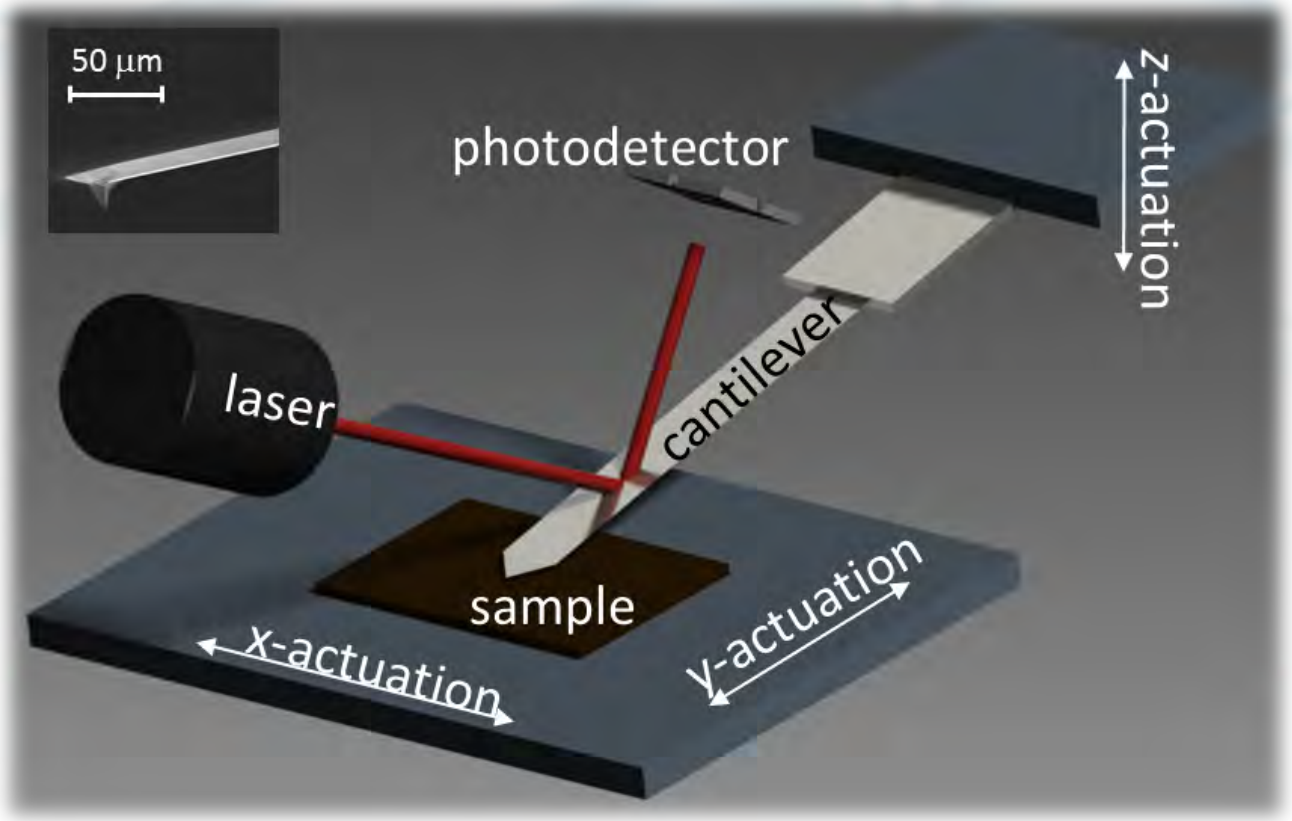


- In-situ oscillatory photo-rheometry
  - Too large
  - Too slow

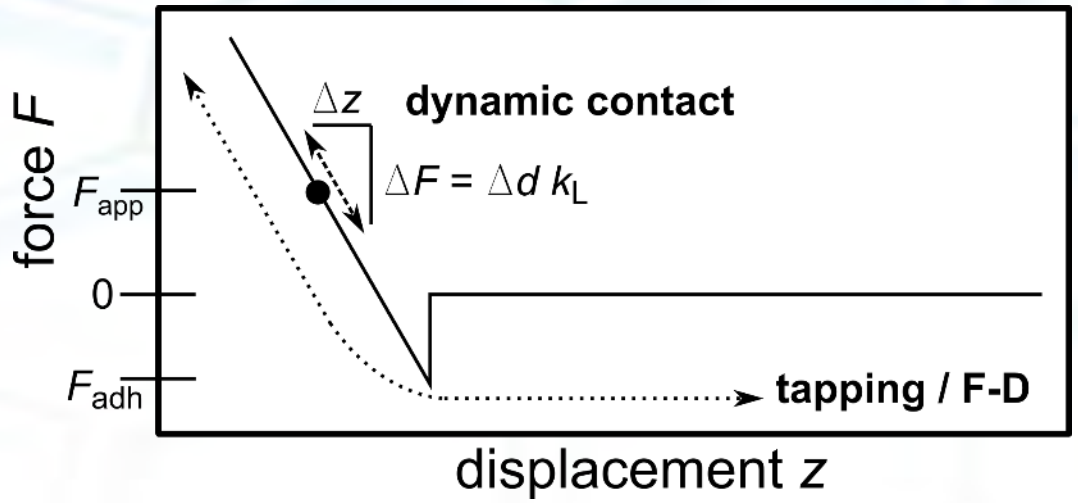
- Maybe AFM is a uniquely suited tool for in-situ?
  - Small
  - Fast (µs)
  - Compatible with monomers?

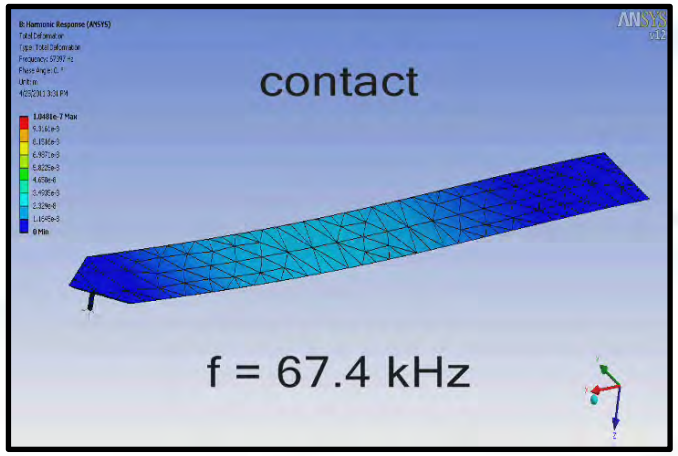
Scanning Probe Microscopy

SPM: Broad class of instruments
AFM: Cantilever force sensor
Nano-positionable
High resolution
Piconewton force sensitivity
Map topography + material properties
Diverse operating environments
    Ambient, UHV, liquids, hot, cold



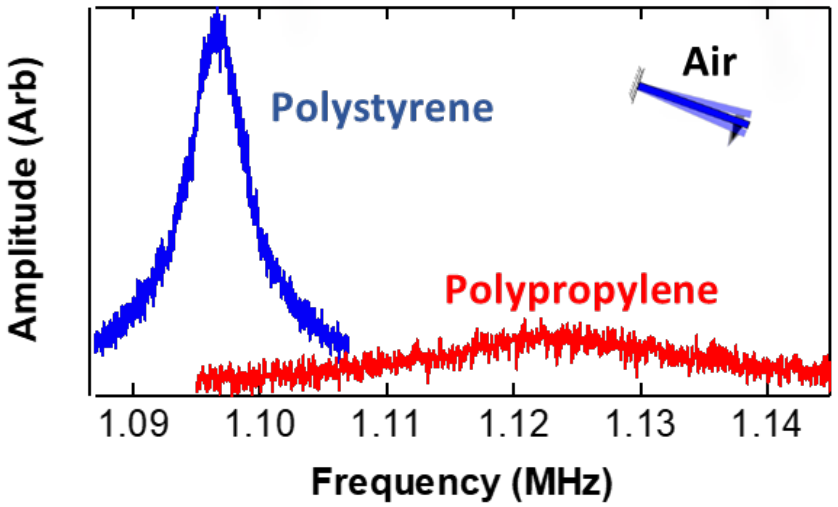
Some background on AFM sensing



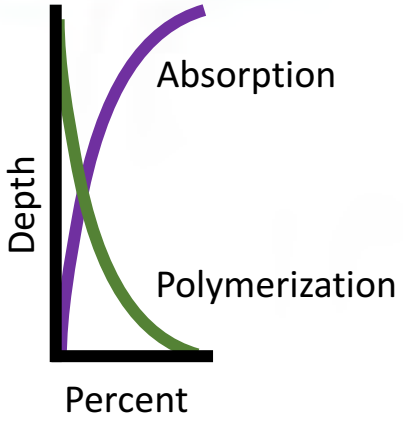


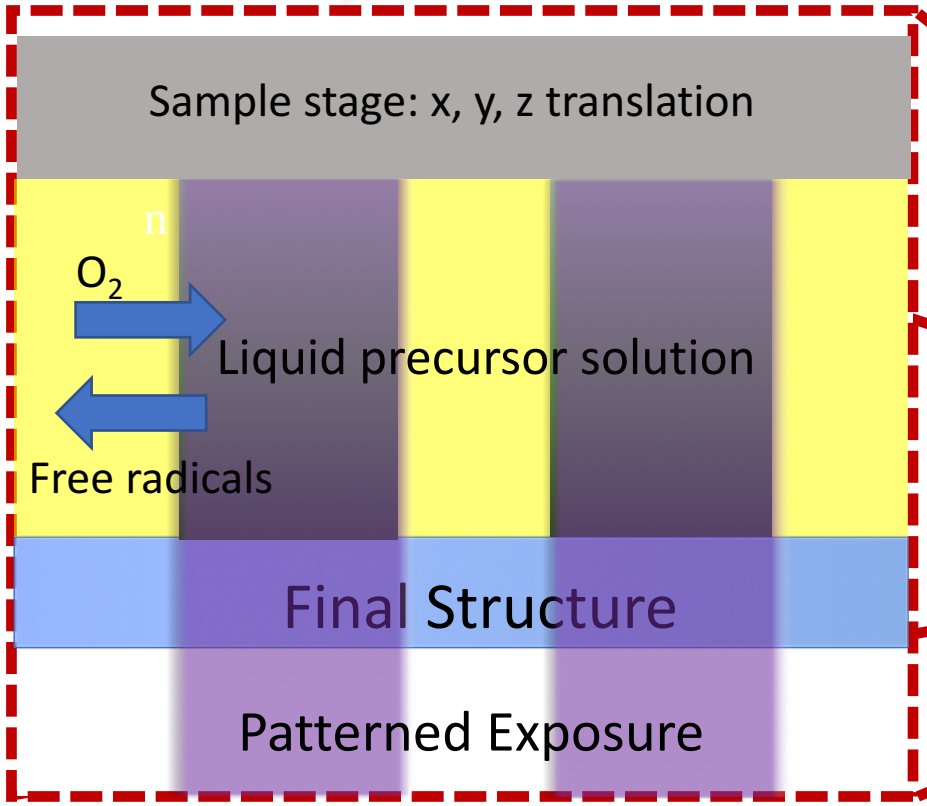
- Static measurement
  - Far below cantilever resonance
  - Measure force from cantilever bending

- Dynamic measurement
  - At cantilever resonance
  - Frequency of resonance ~stiffness
  - Quality factor of resonance ~damping

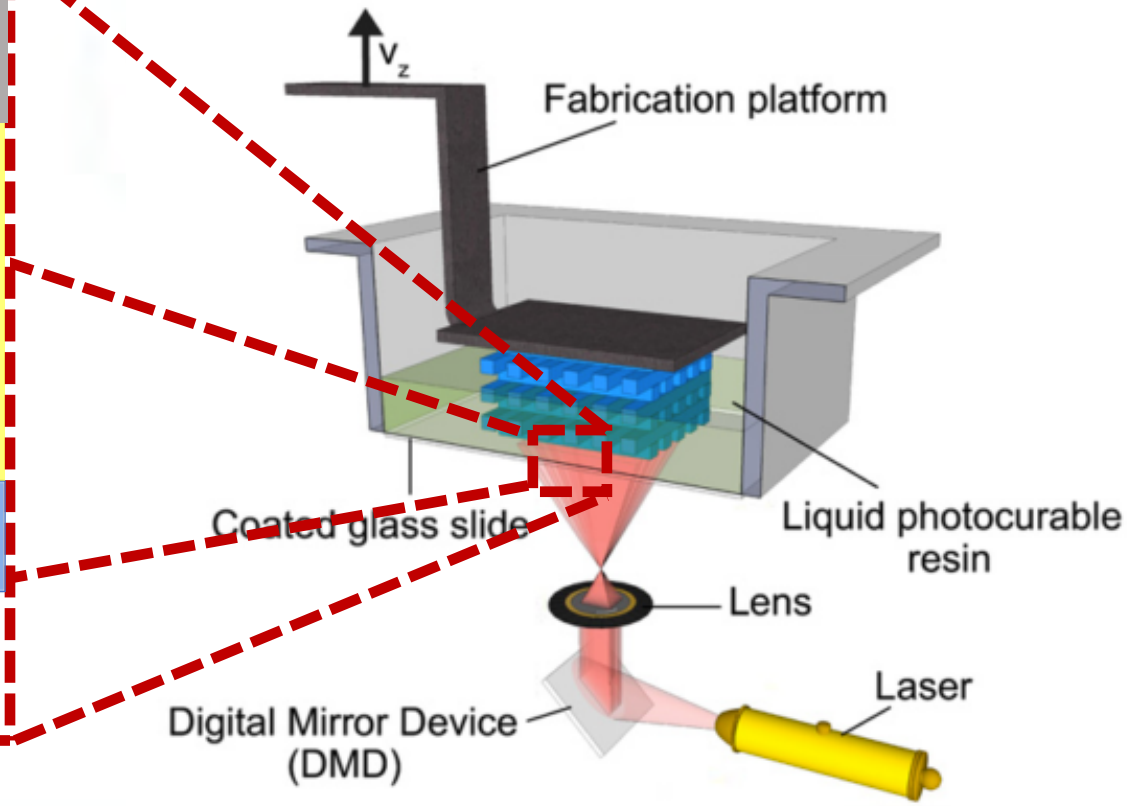


SLA/DLP have inherent mechanical heterogeneity





Stereolithography



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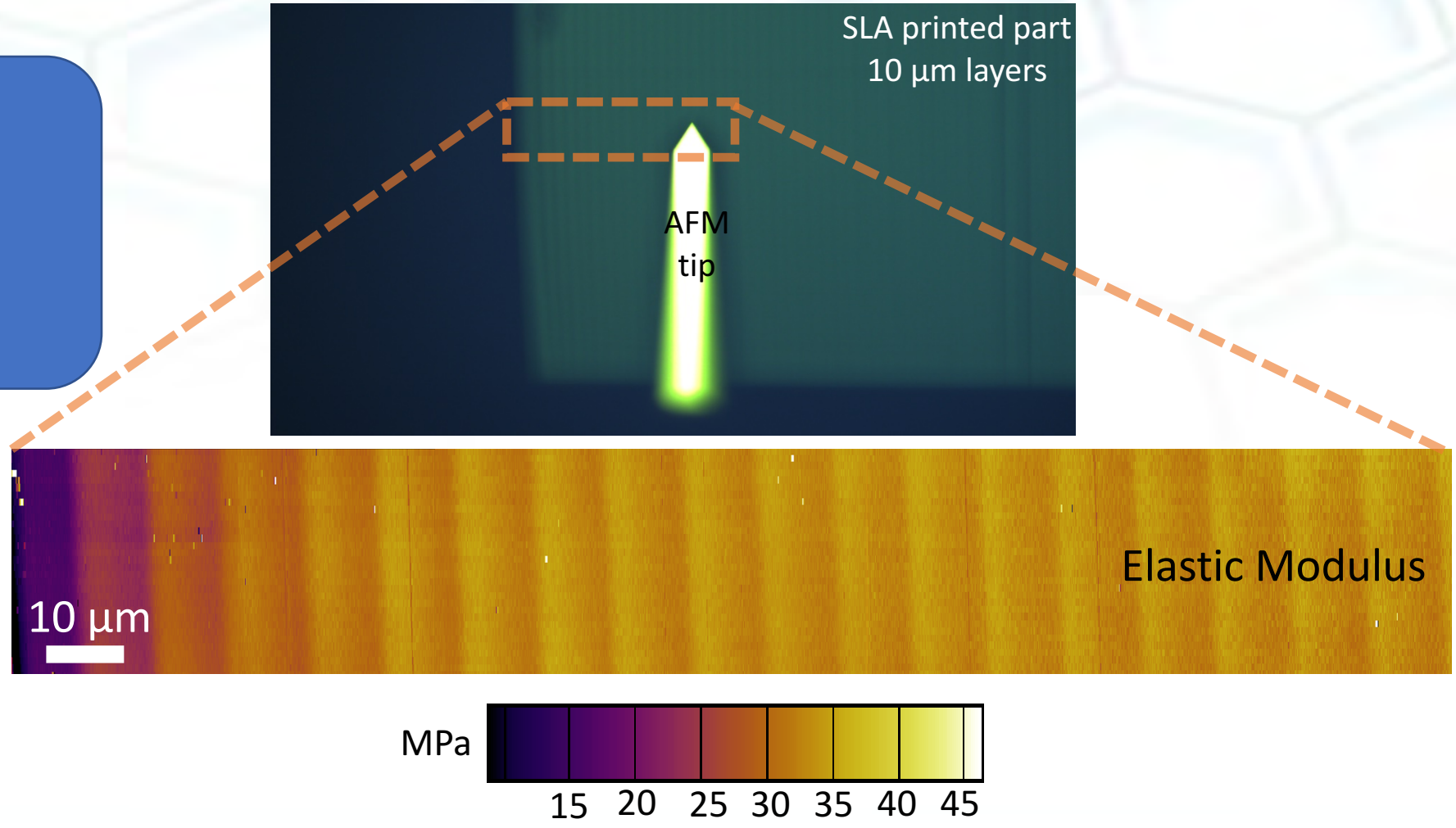
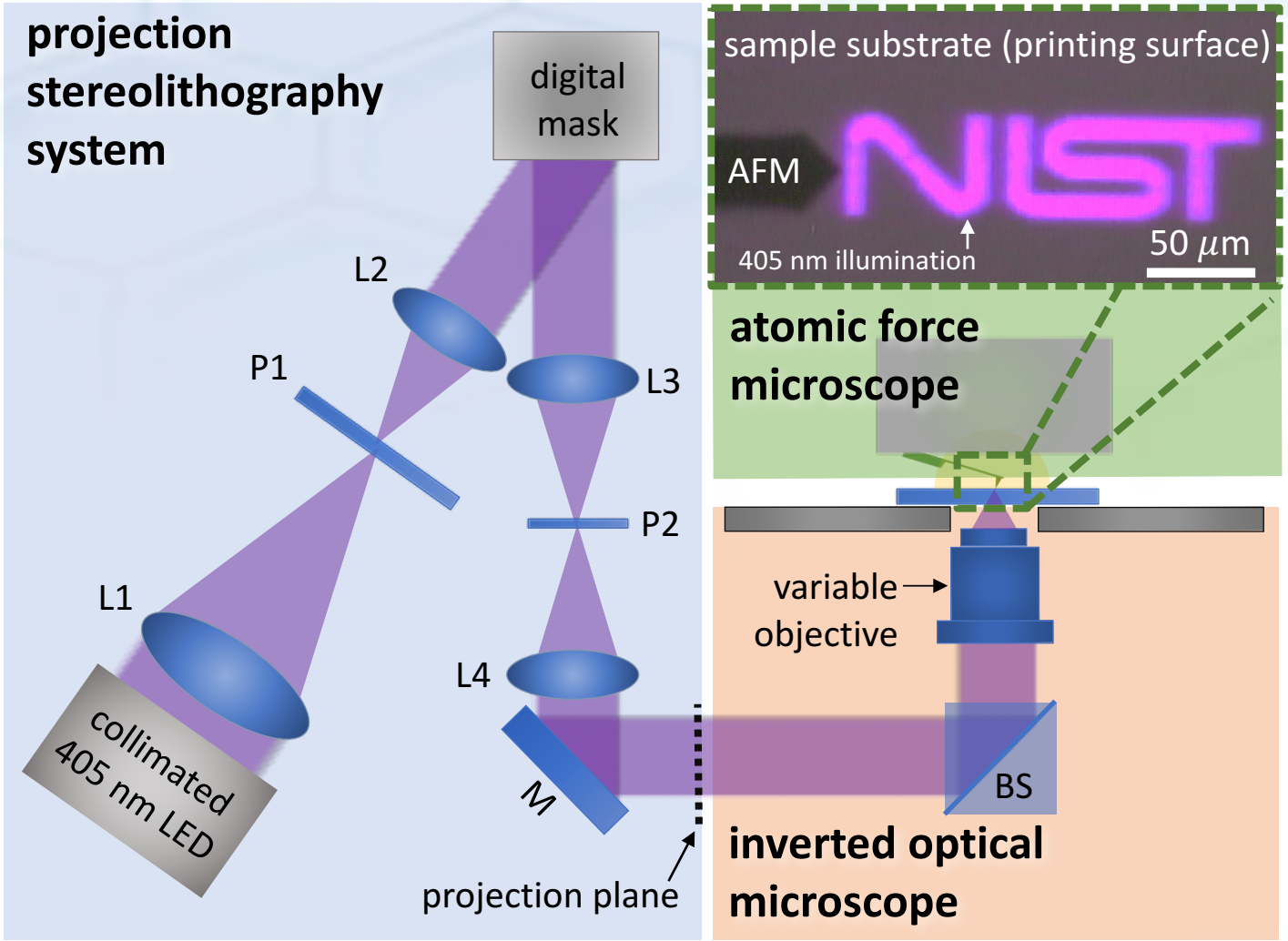
Inherent heterogeneity in SLA parts

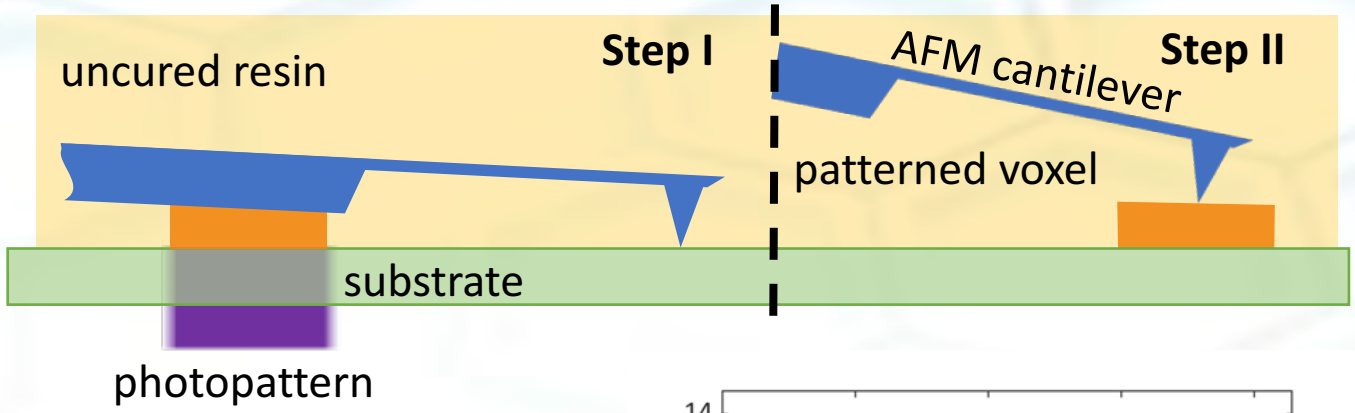
Through-thickness heterogeneity
- Light absorption
- Oxygen inhibition

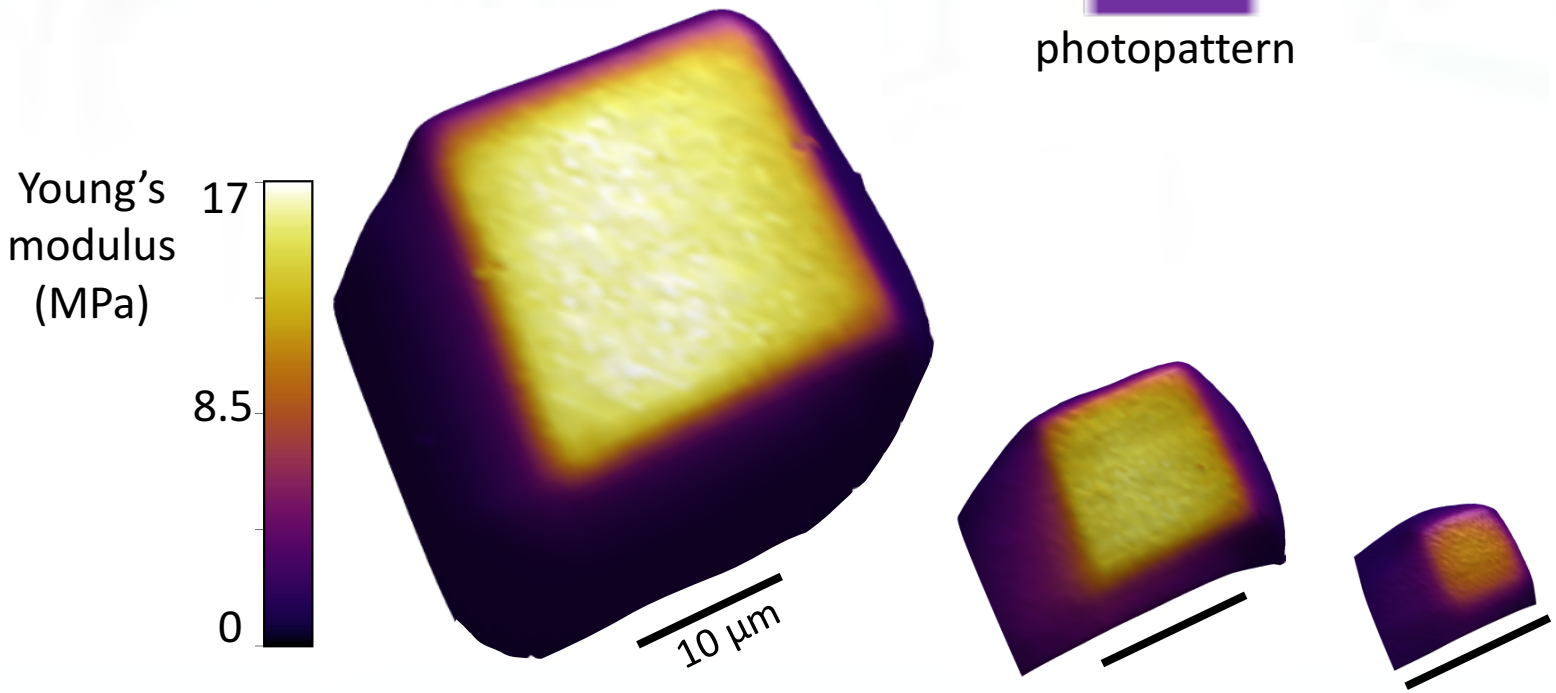


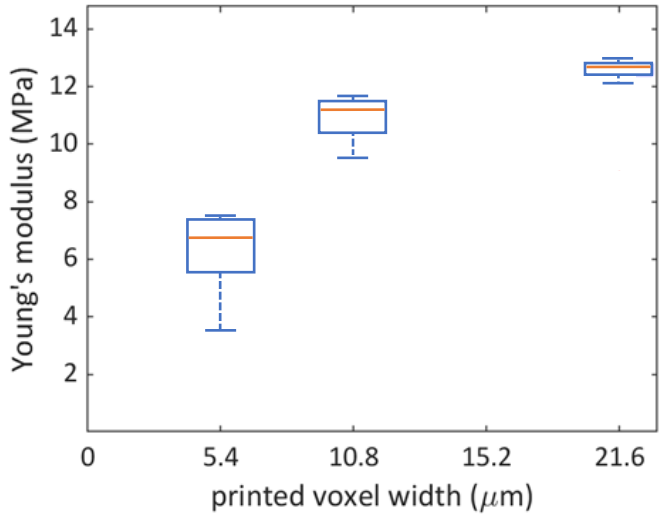
Hybrid AFM 3D Printer



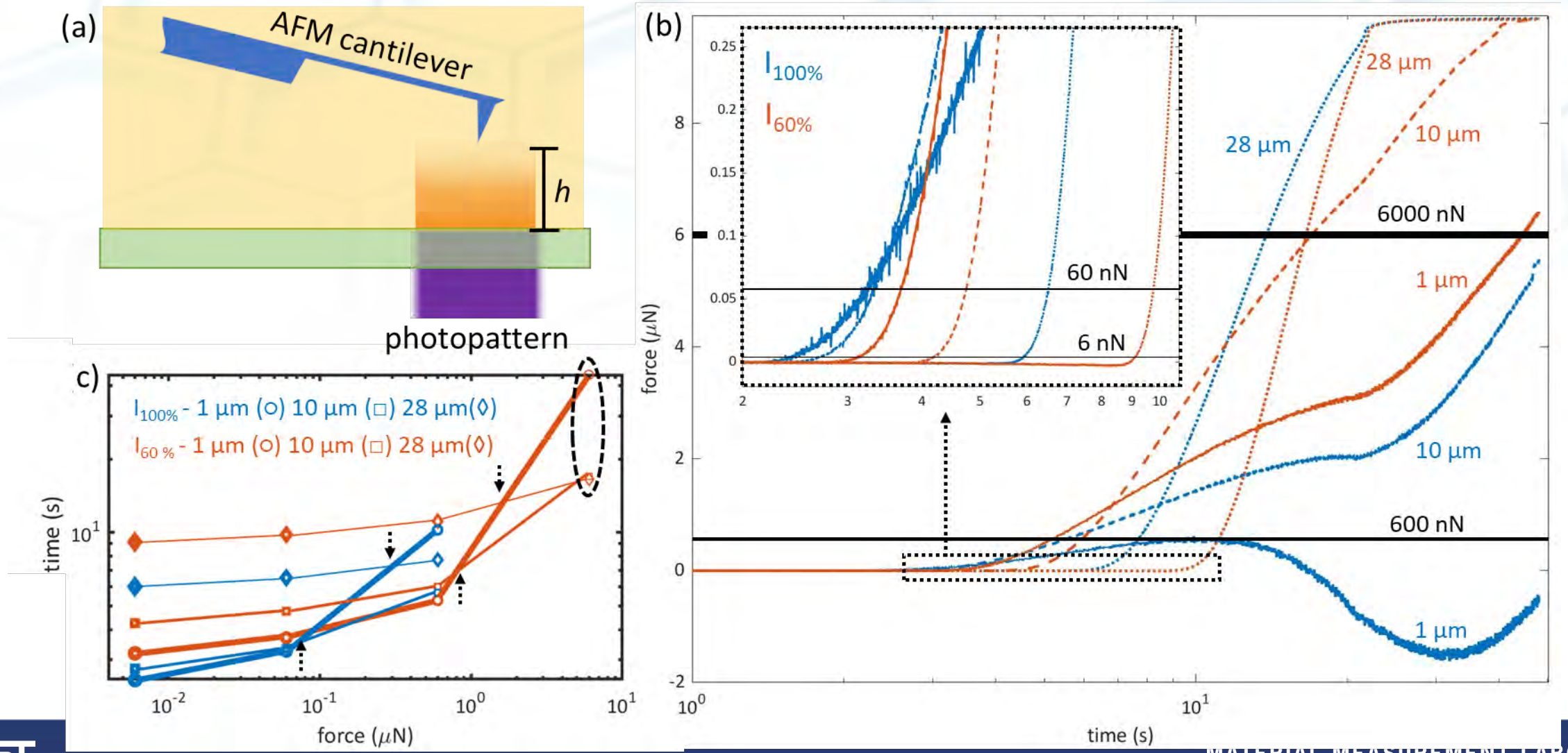
Modality I: In situ polymerization and characterization modes



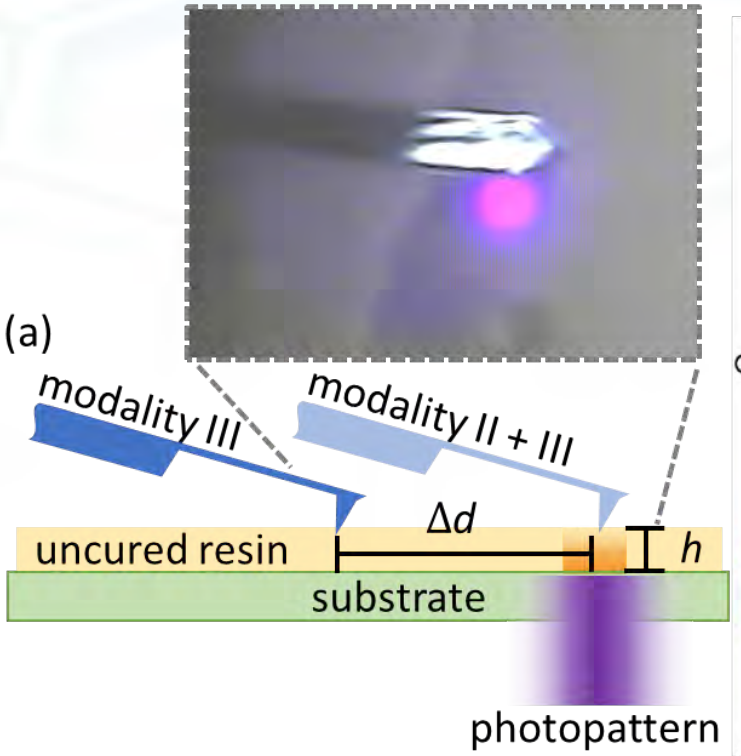


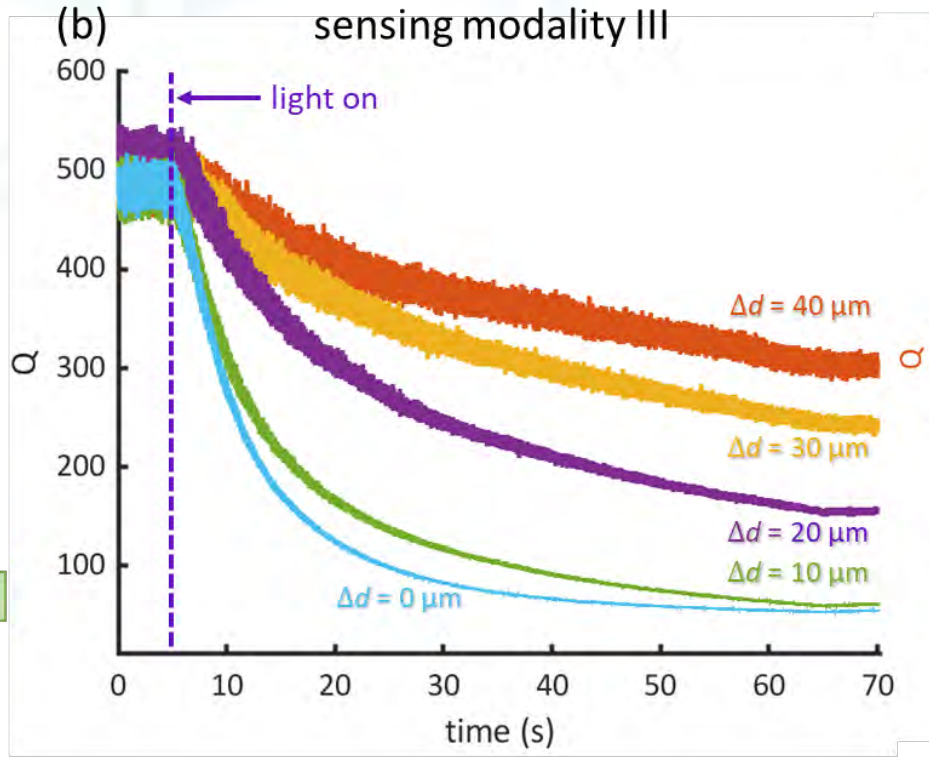


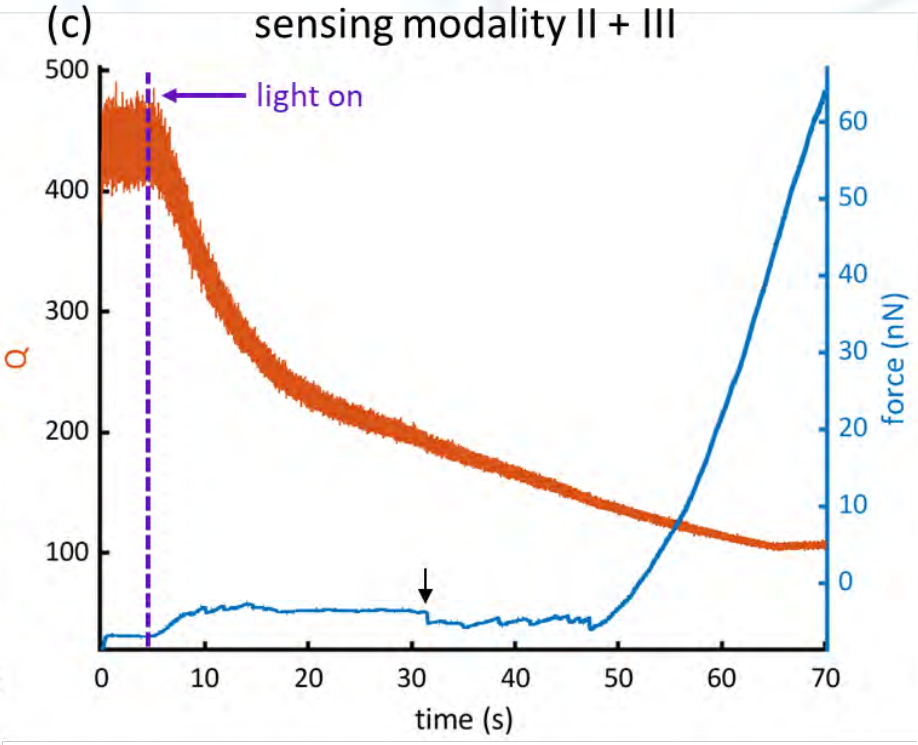
Modality II: In situ cure depth characterization



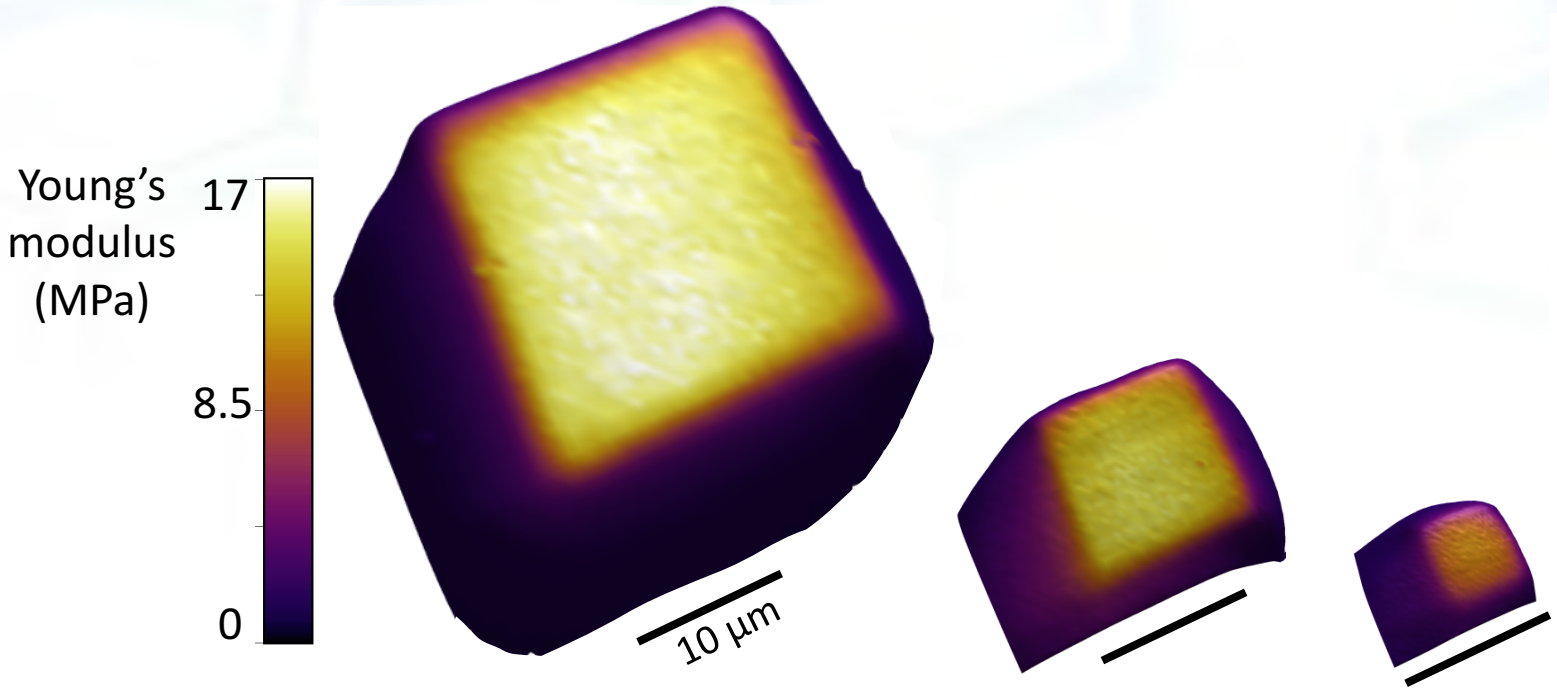
Modality III: In situ dynamic characterization

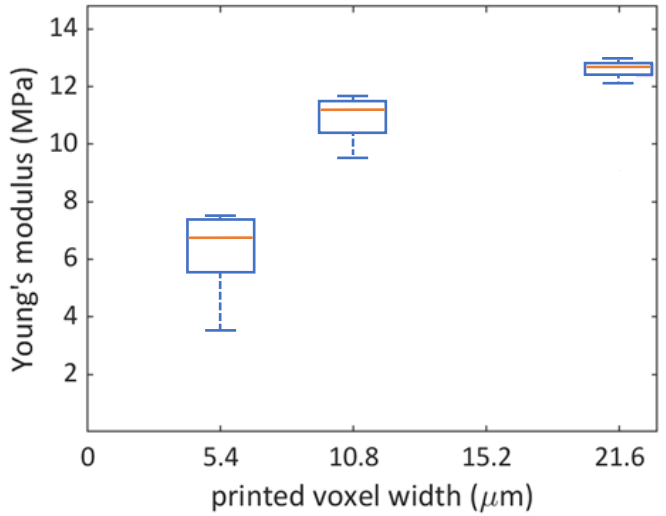






Voxel-scale heterogeneity





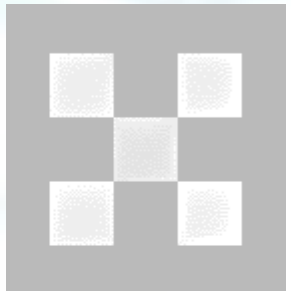
Voxel scale heterogeneity correction

METHOD

exposure mask

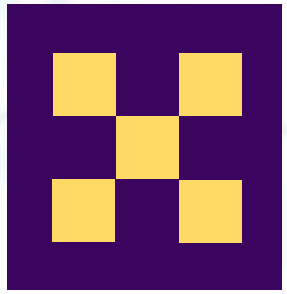
modulus informed correction applied to generate new gray level mask

exposure mask



pattern corrected mask to produce homogeneous photopatterned structure

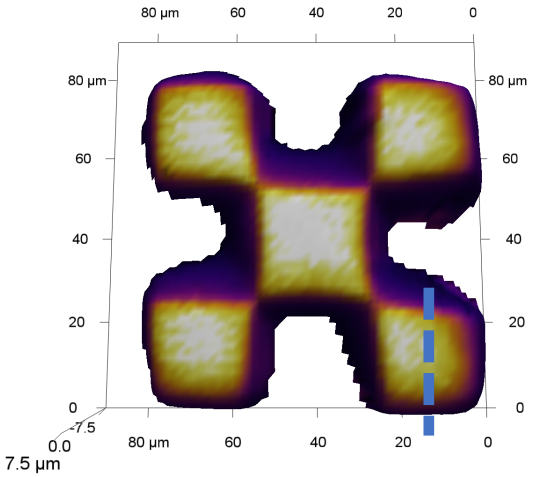
modulus map



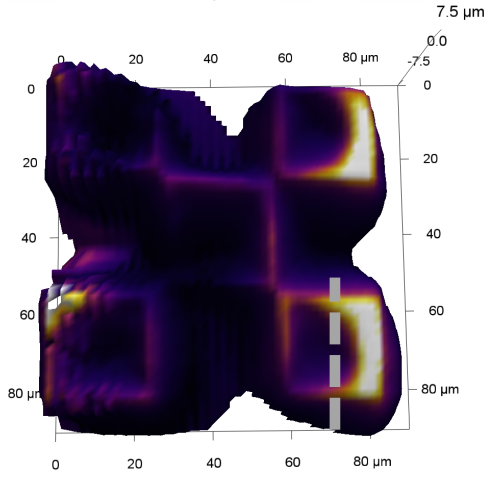
high

low

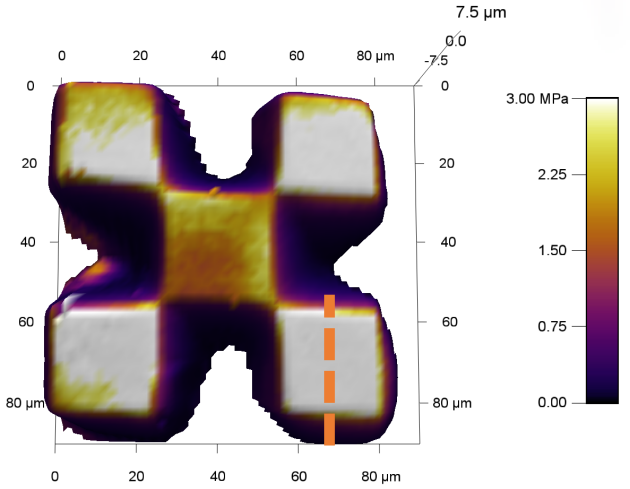
uniform mask



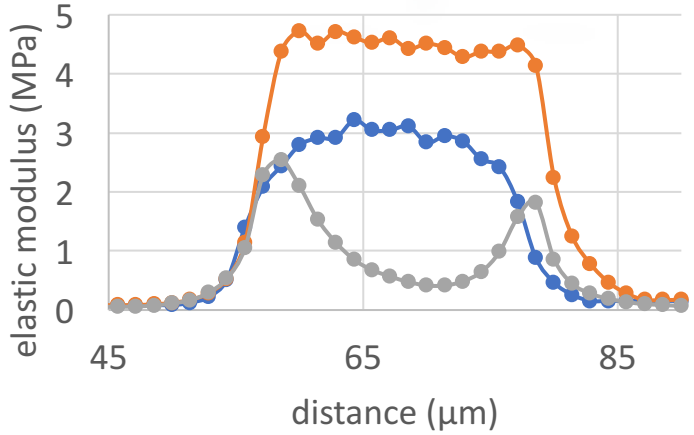
overcorrected, underexposed mask



partially corrected, overexposed mask

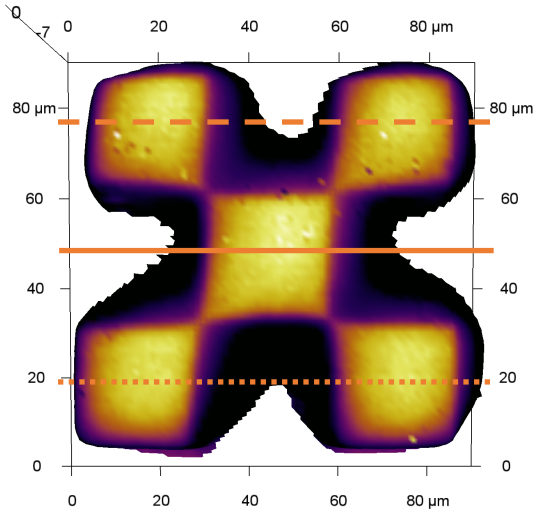


5 pixel-wide line profile

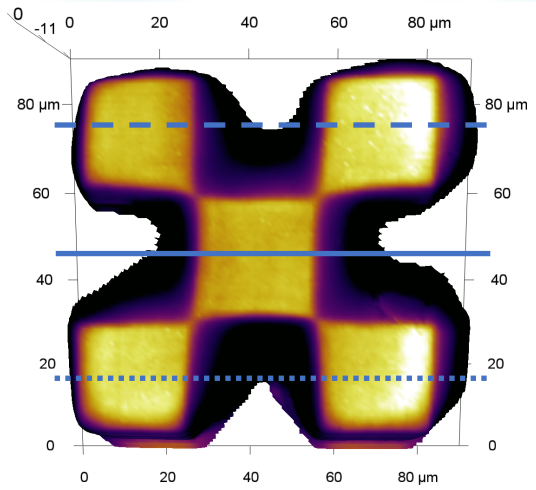


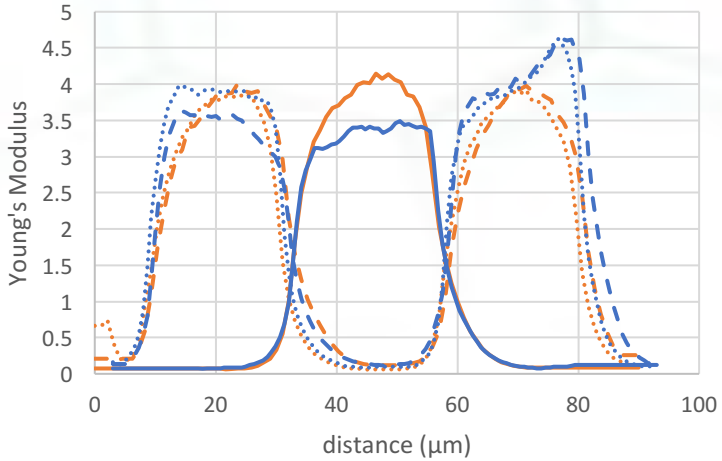
Voxel scale heterogeneity correction

uniform mask



corrected mask





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