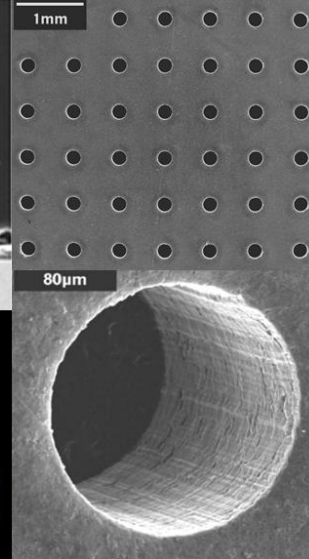
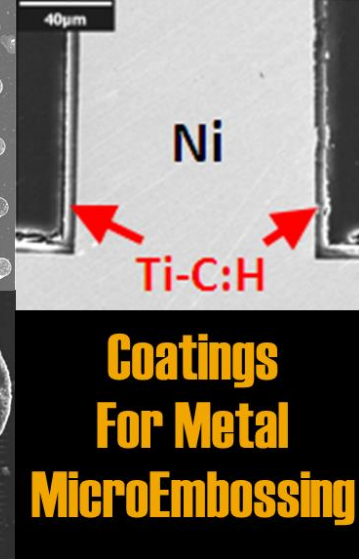
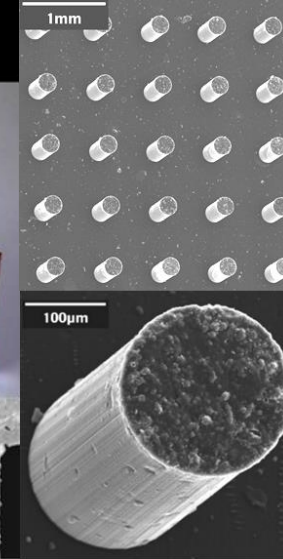
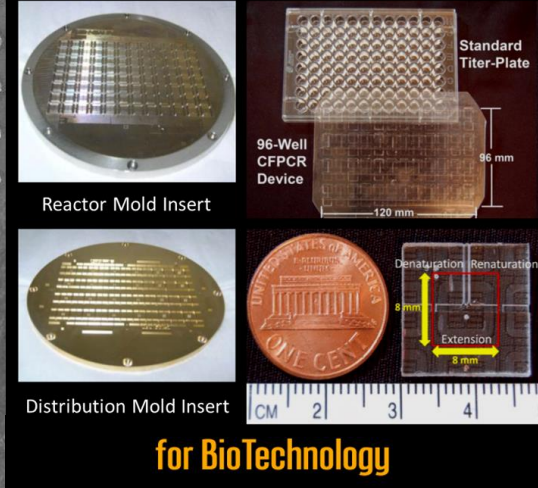


## MicroChannel Heat Exchangers



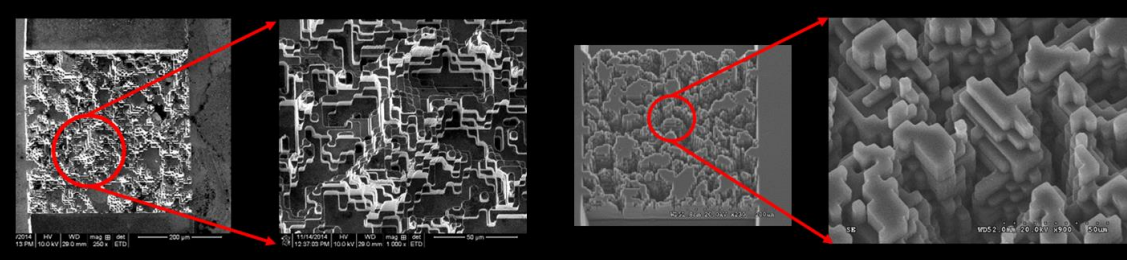
## Polymer MicroFabrication/Fluidics



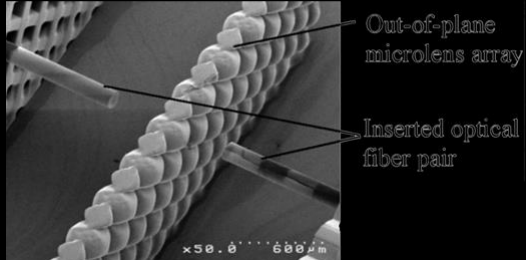
## Coatings For Metal MicroEmbossing

# Replication-based Forming (Embossing) Fabrication/Manufacturing Methods Overview

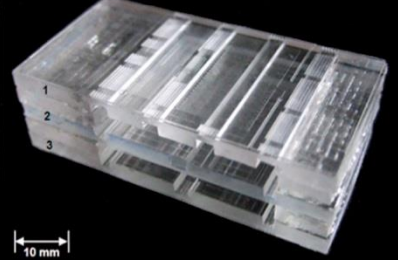
## 3D Multi-Layer Micro-Molding and Embossing



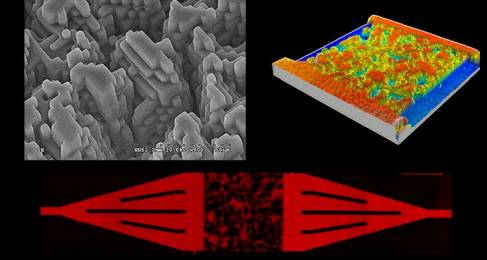
## Microfabrication of Polymer Optics



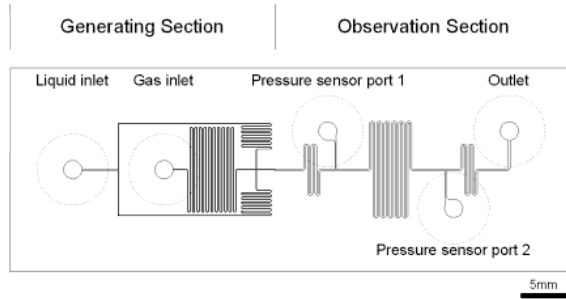
## Polymer MicroFabrication/Fluidics



## 3D Micro-Fluidics MicroFab



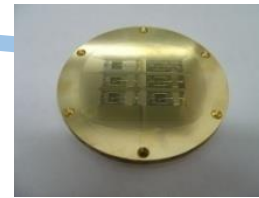
# Micro-Milling and Forming (Embossing) Process



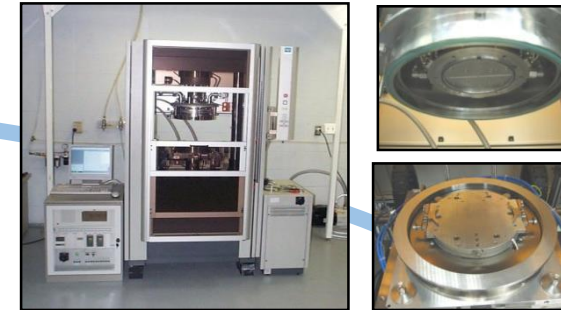
**Design**



**Micro-milling of mold inserts**



**AM<sup>2</sup>F**

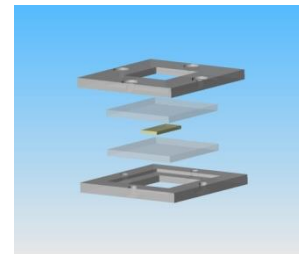


**Hot-embossing**

**CAMD**



**Polymer chips**



**Metrology  
Cutting, drilling  
and cleaning**



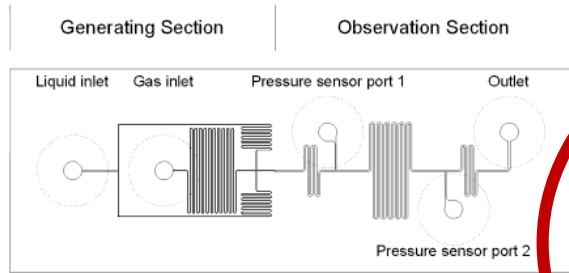
**Thermal fusion bonding**

**M<sup>2</sup>TF**

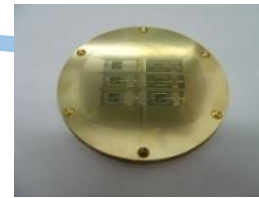


**Embossed Polymer plates  
(PMMA, PC, COC)**

# Micro-Milling and Forming (Embossing) Process

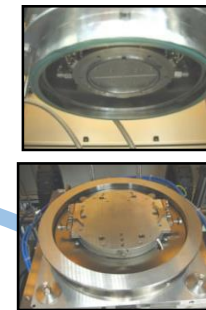


**Design**



**AM<sup>2</sup>F**

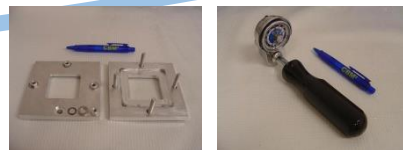
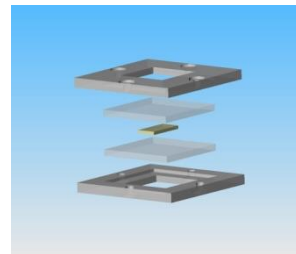
**Micro-milling of mold inserts**



**CAMD**

**Hot-embossing**

**Metrology  
Cutting, drilling  
and cleaning**



**M<sup>2</sup>TF**

**Thermal fusion bonding**

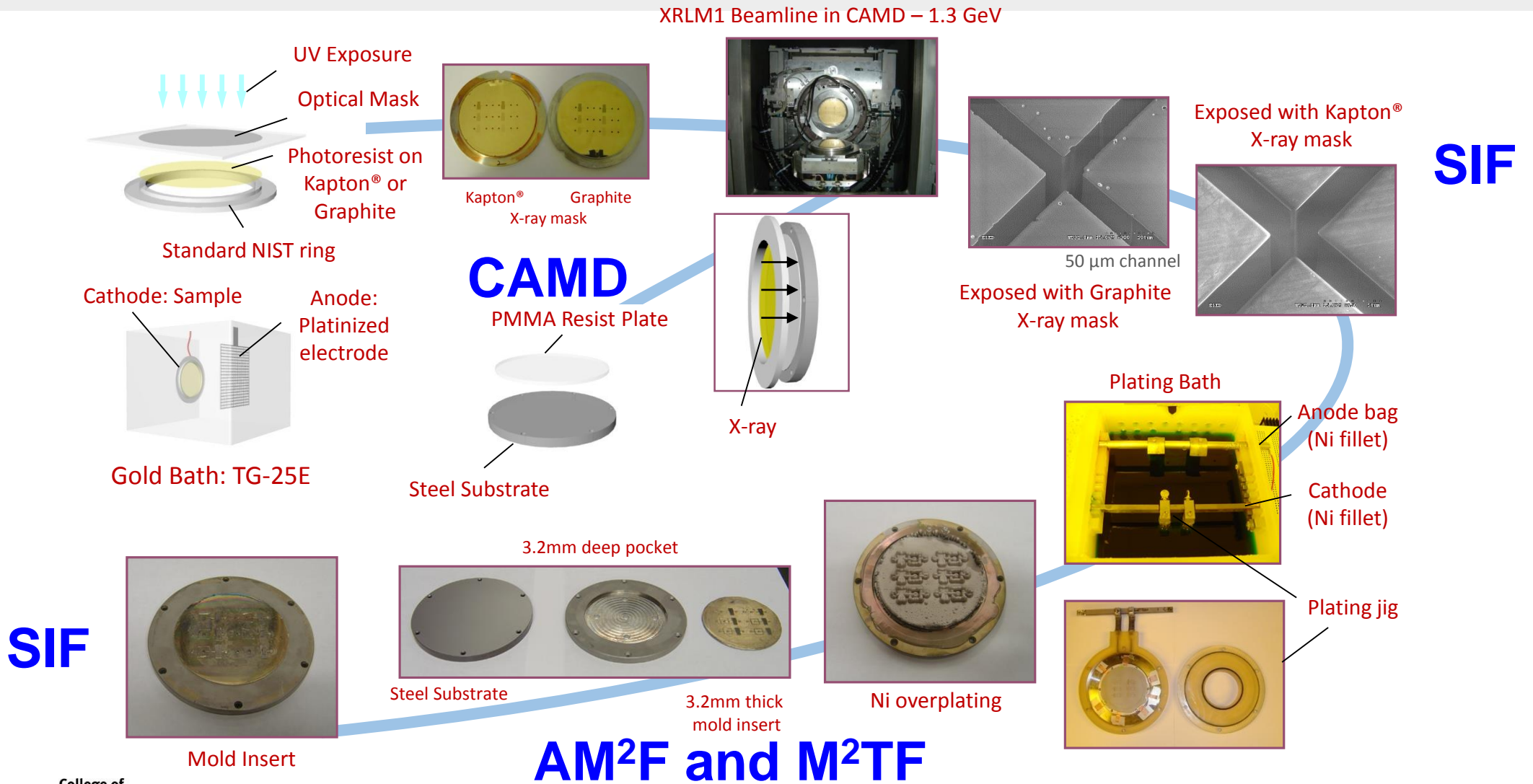


**Embossed Polymer plates  
(PMMA, PC, COC)**

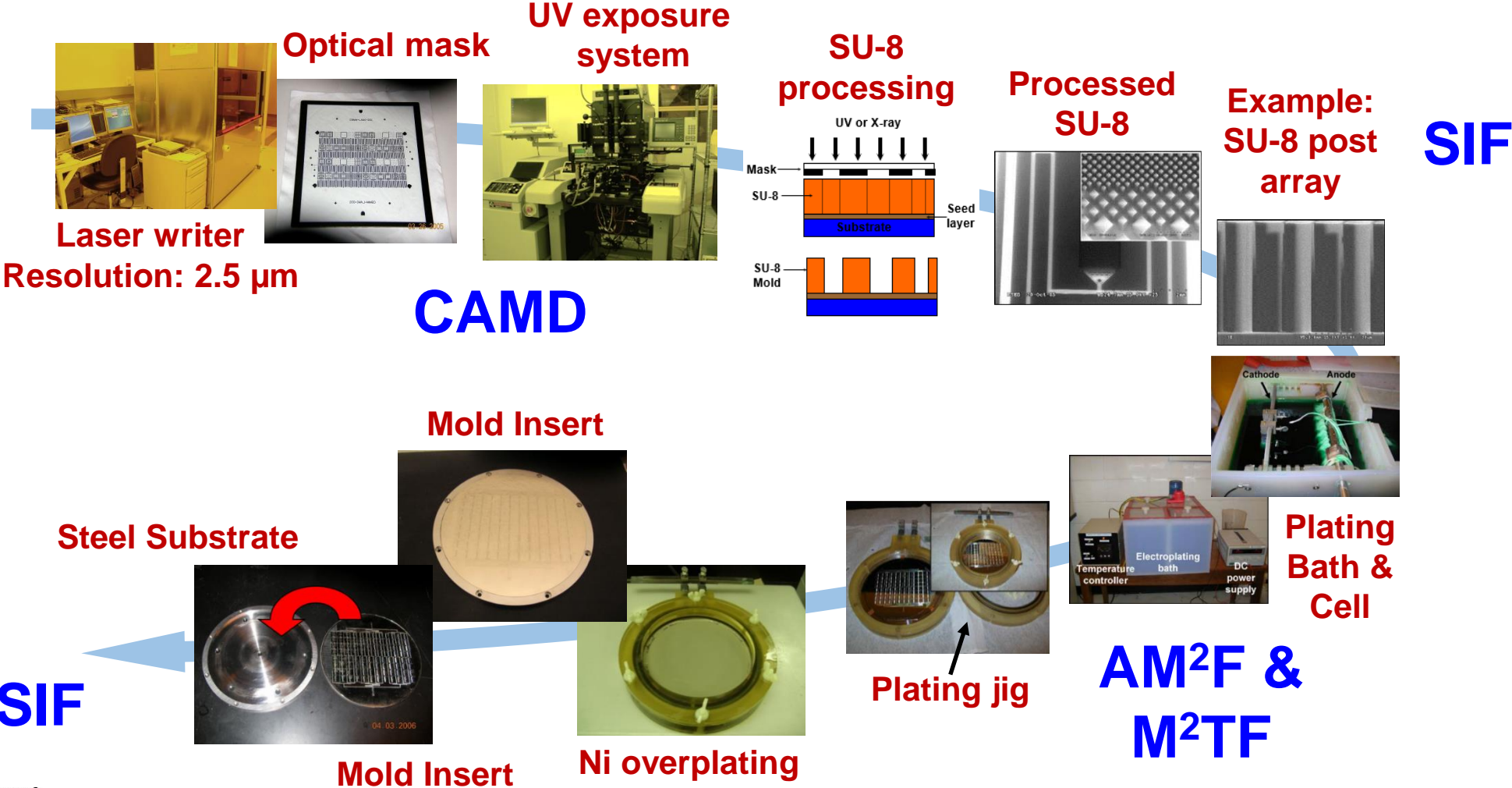


**Polymer chips**

# Mold Insert Fabrication: LiGA Process (X-Ray)

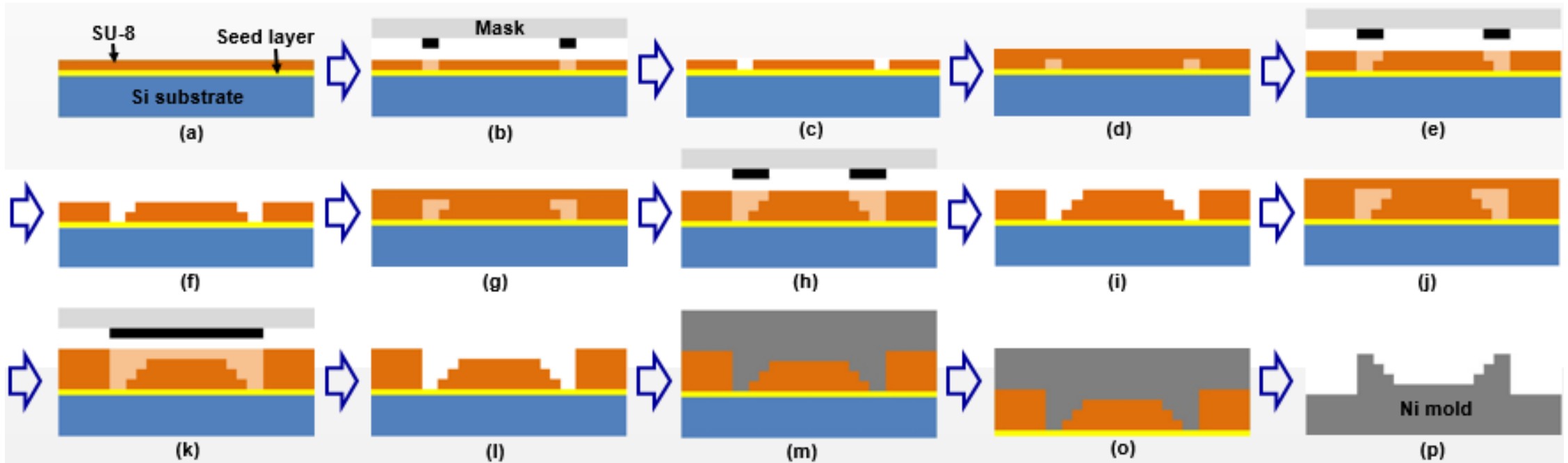


# Mold Insert Fabrication: LiGA Process (UV in SU-8)



# High-Resolution, Multi-Layer Mold Inserts

## SU-8, multi-layer lithography process



Nickel molds in **13 layers** have been made by electroforming with **smallest features of 5- $\mu\text{m}$**

Replication-based Forming (Embossing) Nano/Micro/Mezo-Fabrication

# Example Outcomes in Metals

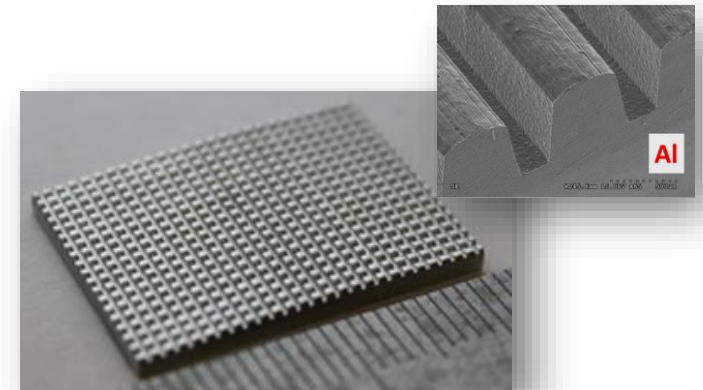
# Consortium for Innovation in Materials and Manufacturing



## **Multi-Scale Metal Forming**

**Coatings and Interfaces**

**Replication-Based Manufacturing**

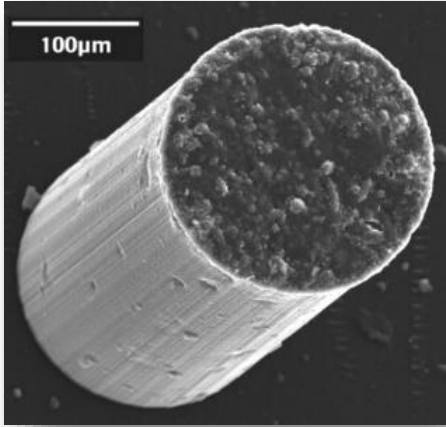




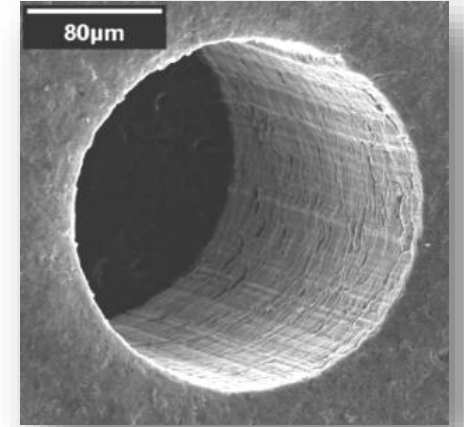
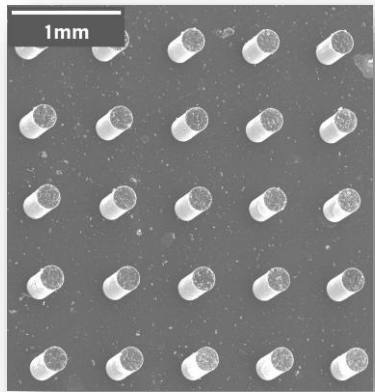
# Thin-Film Coatings for Mold Inserts



Hard, low-friction coatings through Inductively coupled plasma (ICP) assisted PVD.

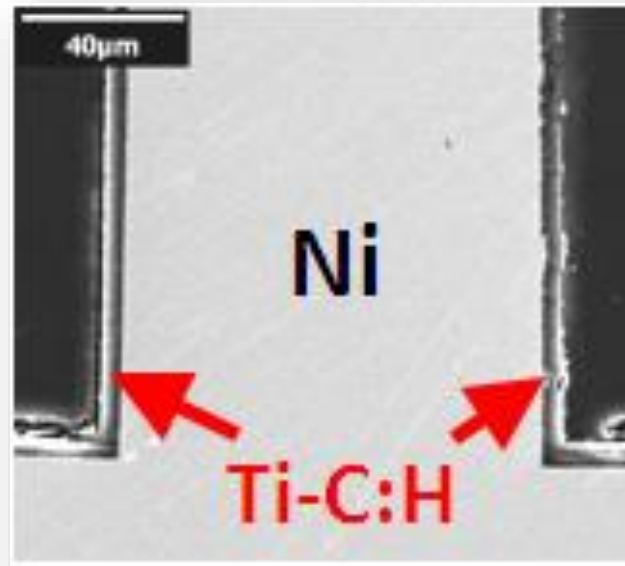


Ni micro-post mold insert



Micro-hole array in Al

Coating: Enabling Technology



M<sup>2</sup>TF

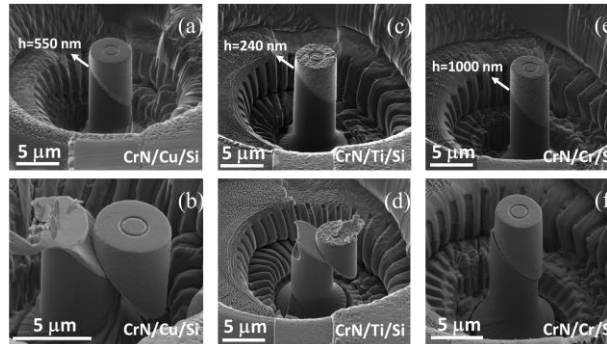
Wenjin Meng's Group

# Solid/Solid Interfacial Mechanical Integrity

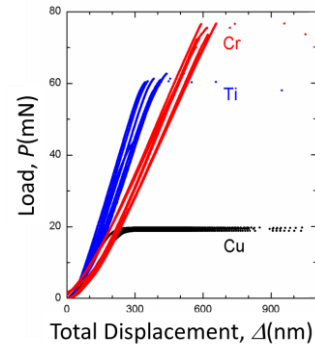
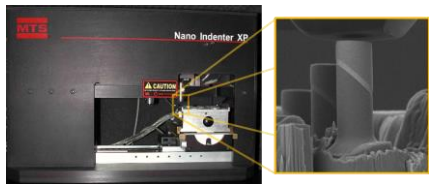


Measure & Understand  
Interfacial Strength & Failure  
ICME Approach

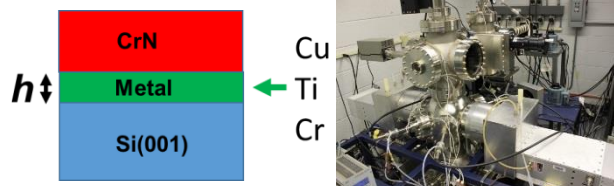
Axial Compression Test



Diamond punch on  
FIB milled post



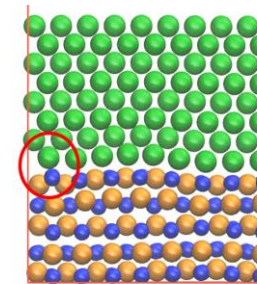
Interface Synthesis



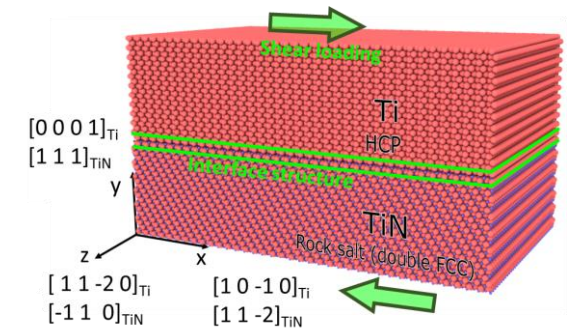
Development of continuum models with interfacial physics

MD Simulations and Dislocation Dynamics

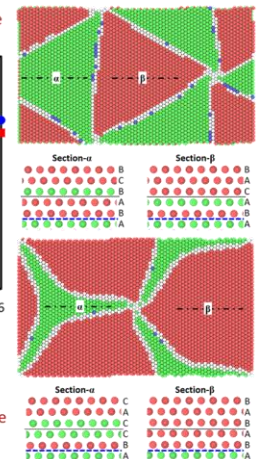
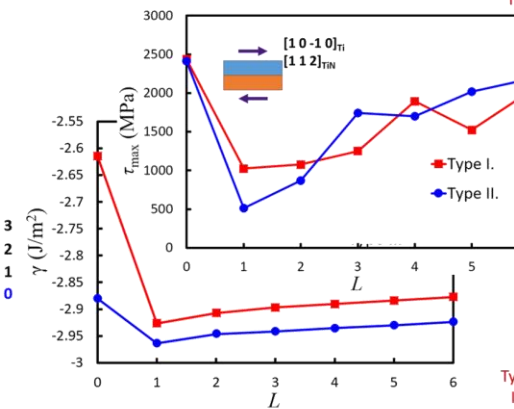
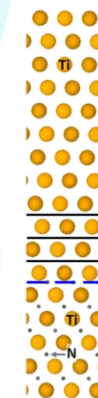
Edge dislocation  
“unlocks” interface



HPC, Loni



Failure at one atomic level away  
from chemical interface



SIF

M<sup>2</sup>TF



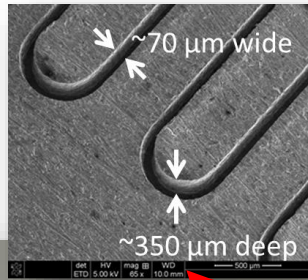
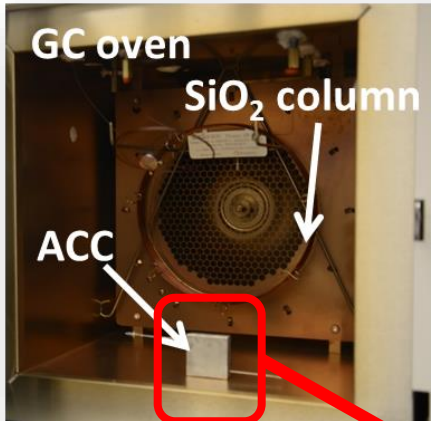
College of  
Engineering  
Department of  
Mechanical & Industrial Engineering

Wenjin Meng & Shuai Shao Groups

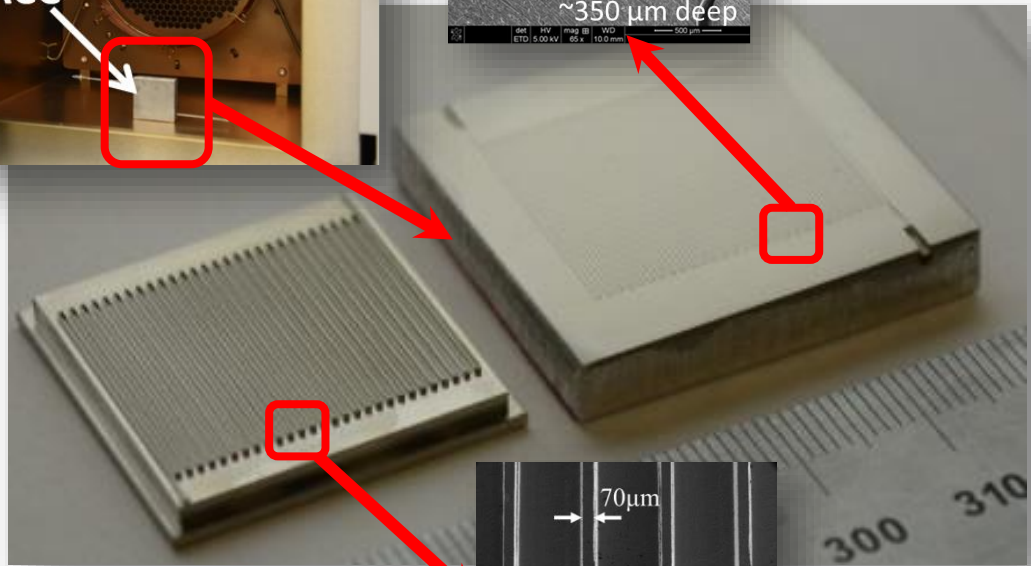
# Metal Micro-Forming (Embossing)



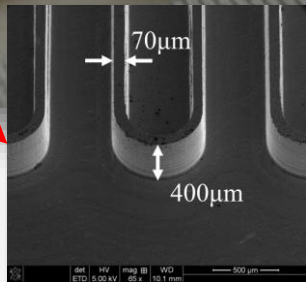
## Gas-Chromatograph Chip in Aluminum (ACC)



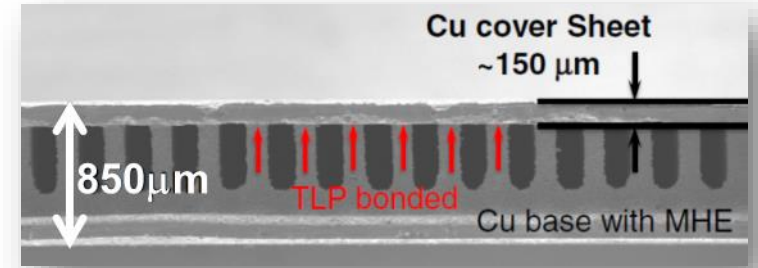
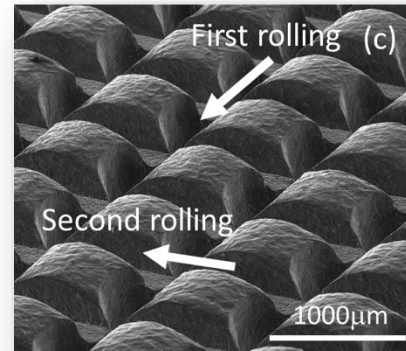
**Formed Channels**



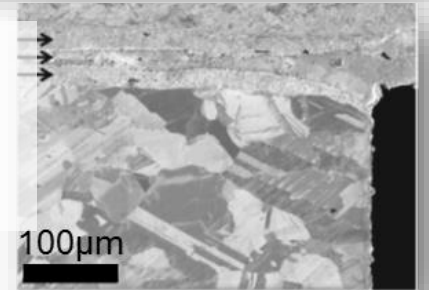
**Mold Insert**



## Textured Metal Surfaces



**Transient Liquid Phase (TLP) bonded cover**



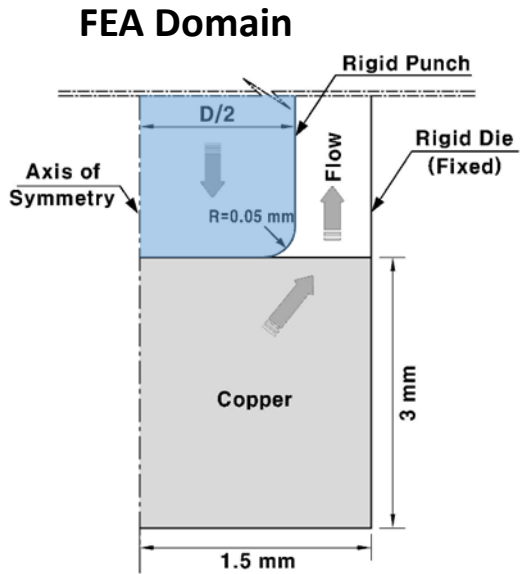
## Micro-Channel Heat Exchanger



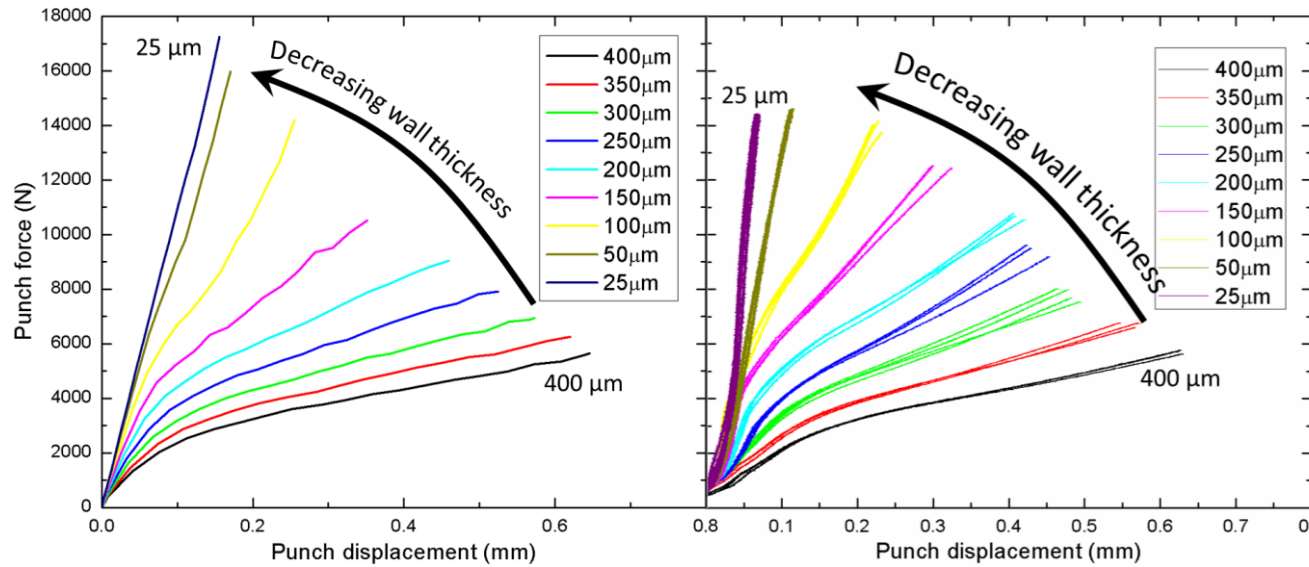
**AM<sup>2</sup>F & M<sup>2</sup>TF**

Wenjin Meng's Group

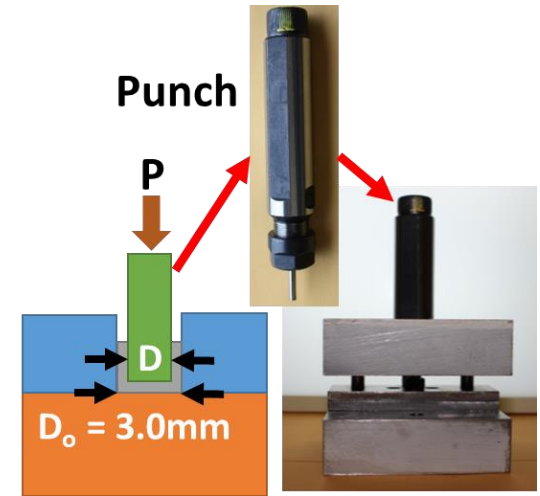
# Micro-Scale Reverse Extrusion



## Continuum Plasticity FEA Simulation Result ~ Experimental Result

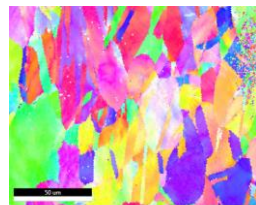
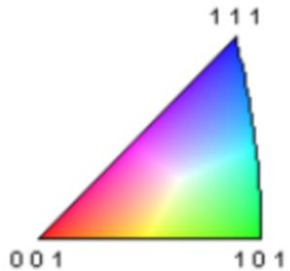


## Reverse Extrusion Experiment

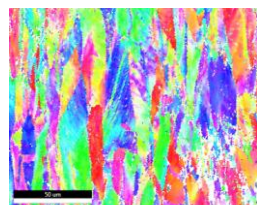


## Top view of extruded sample

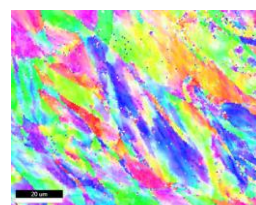
## Associated Electron BackScatter Diffraction (EBSD) maps



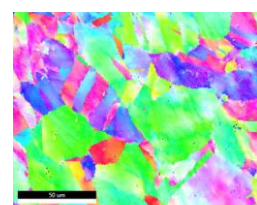
Area 1



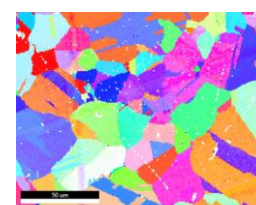
Area 2



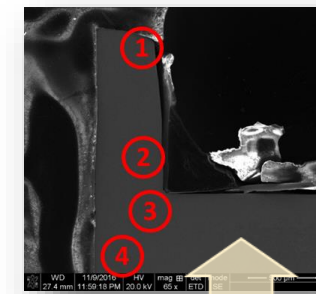
Area 3



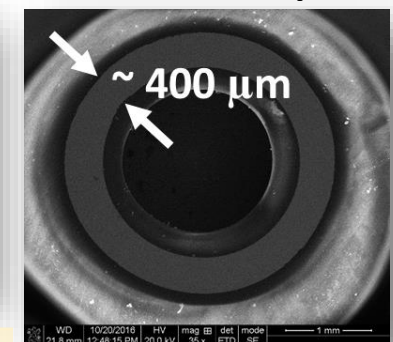
Area 4



Annealed



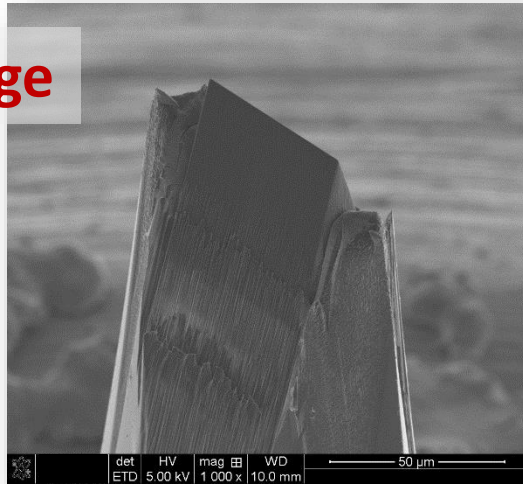
SEM image of transverse cross-section of extruded Cu samples



# Nano-Scale Replication (Forming / Embossing)

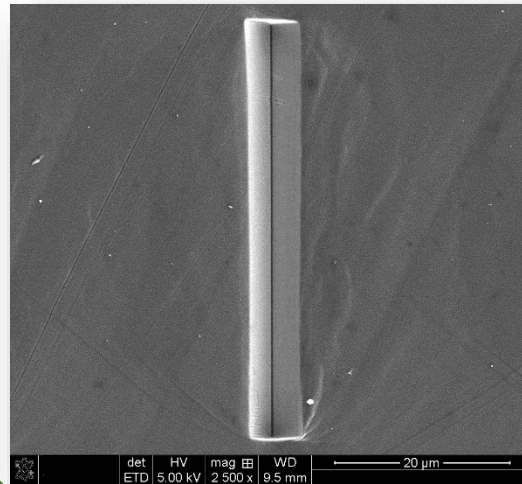


Wedge

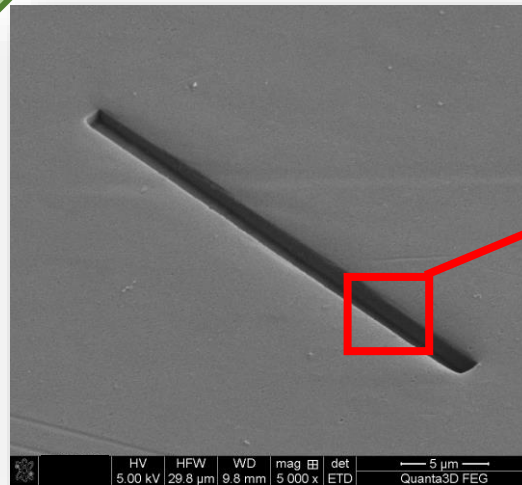
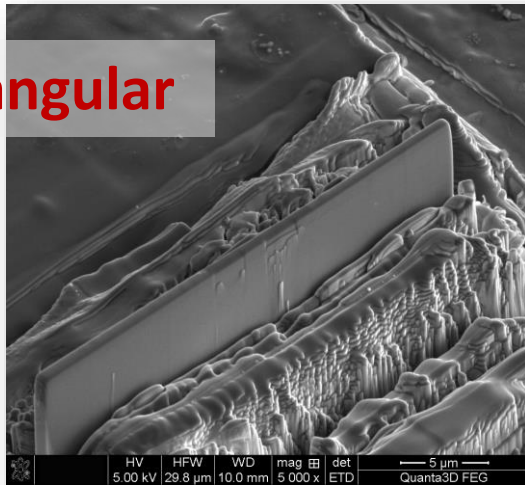


FIB Milled Diamond Tools

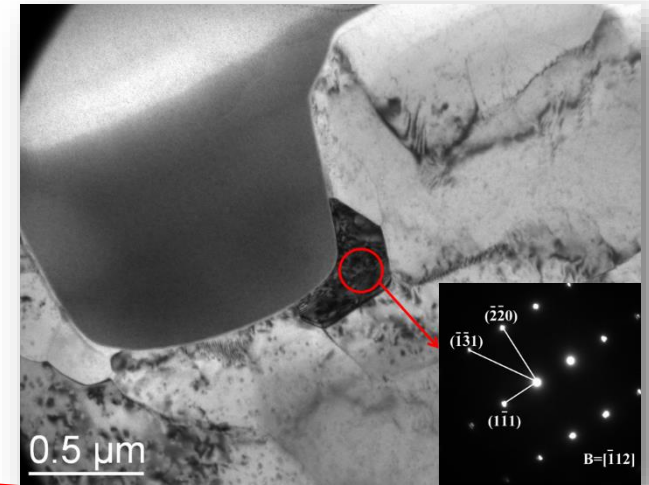
Nano-Embossings in Aluminum



Rectangular



Material structure underneath imprint

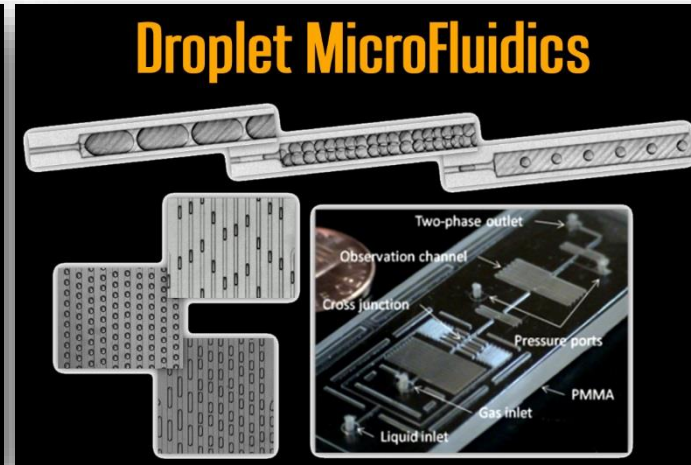
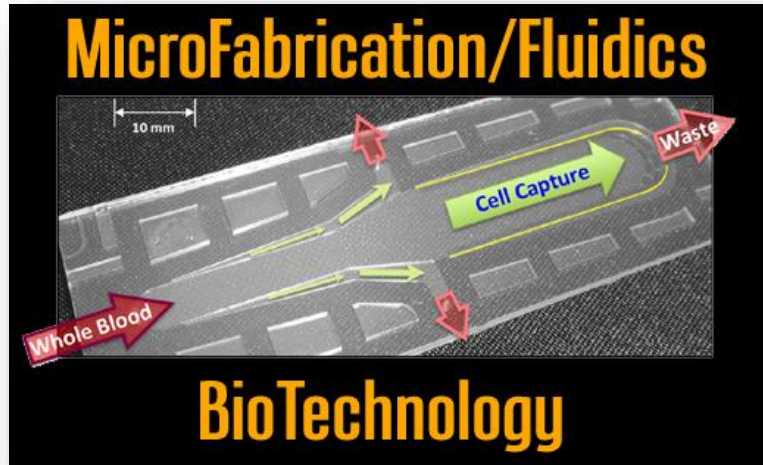


TEM

Replication-based Forming (Embossing) Nano/Micro/Mezo-Fabrication

# Example Outcomes in Polymers

# Polymer Products for Applications

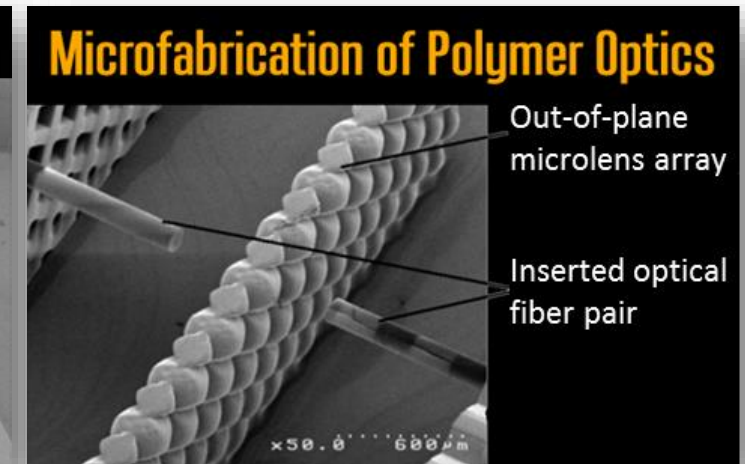
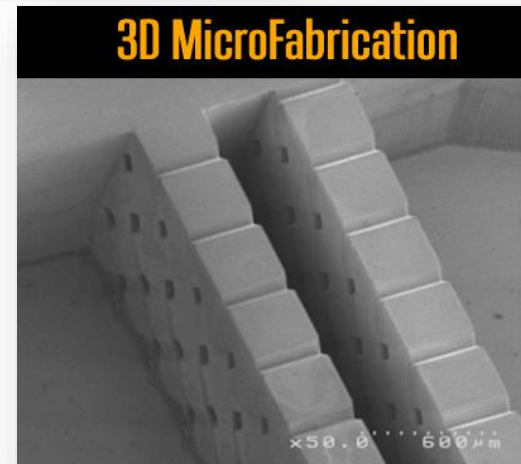


Single-layer embossed products in PMMA and PC for BioTechnology applications (features down to 25  $\mu\text{m}$ )

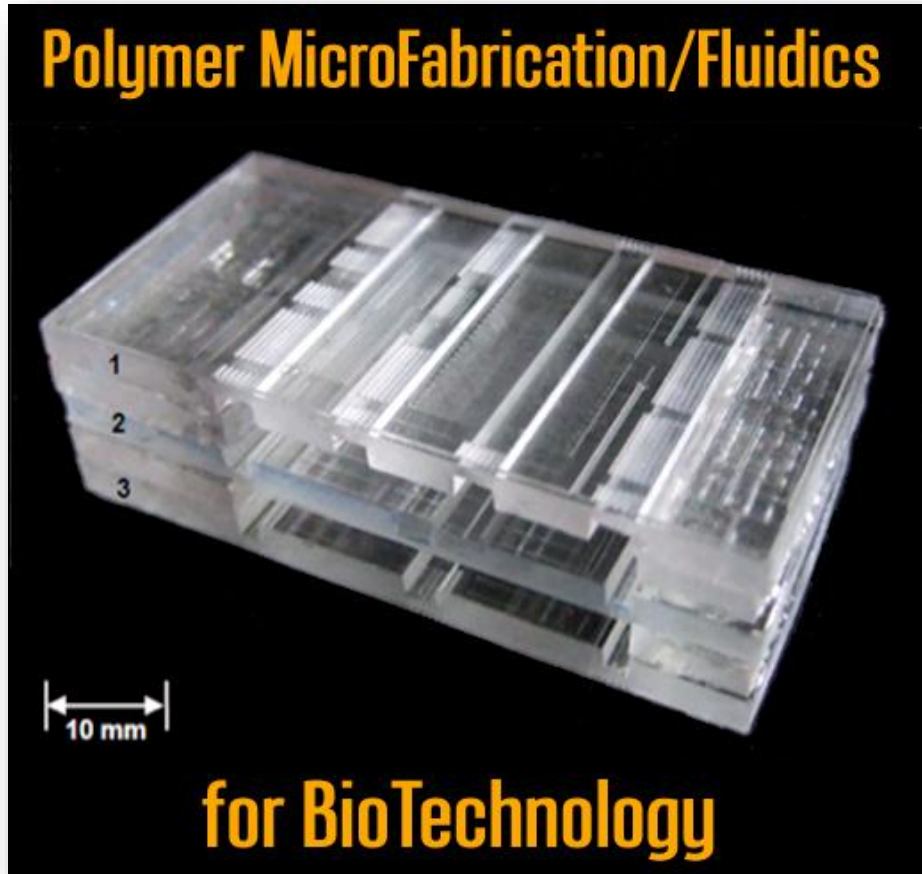
Daniel Park, Mike C. Murphy,  
Dimitris E. Nikipoulos

3D products in SU-8 by means of UV lithography for BioTechnology applications (features down to 75  $\mu\text{m}$ )

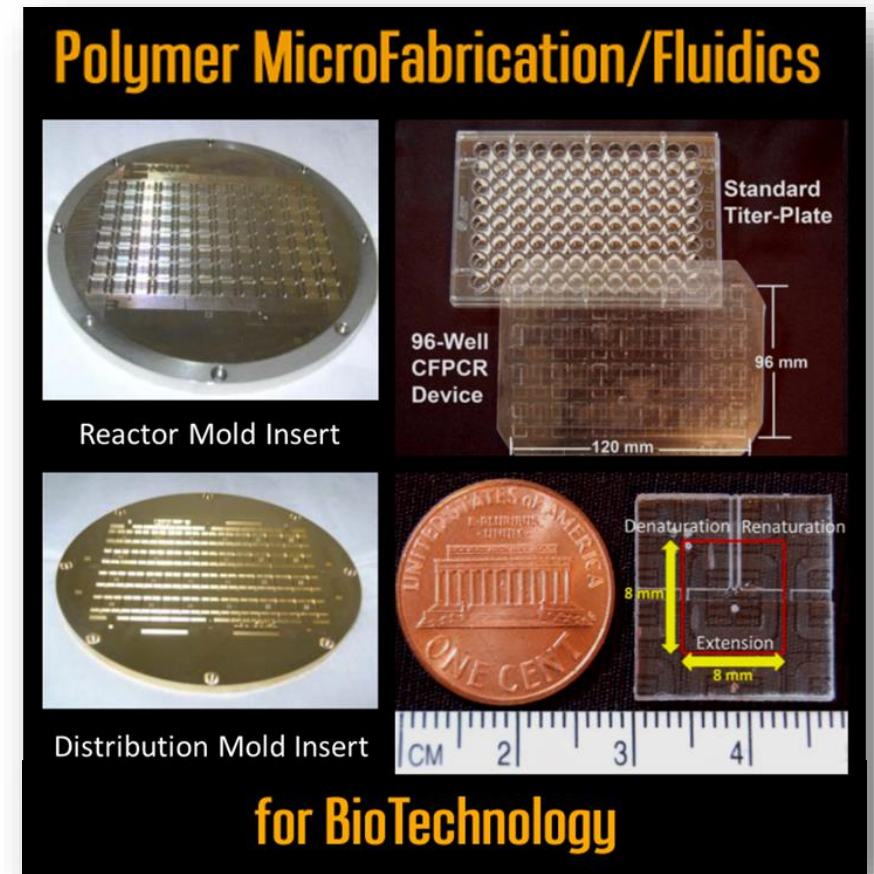
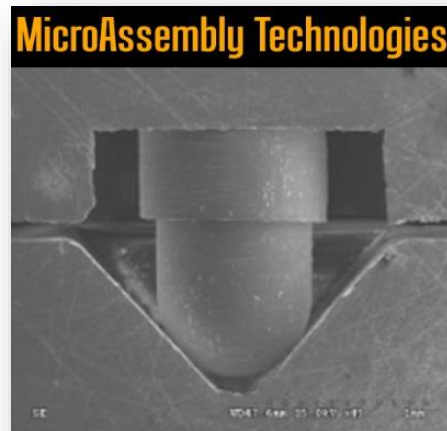
Wanjun Wang's Group



# Complex Embossed Assembled Products for Applications

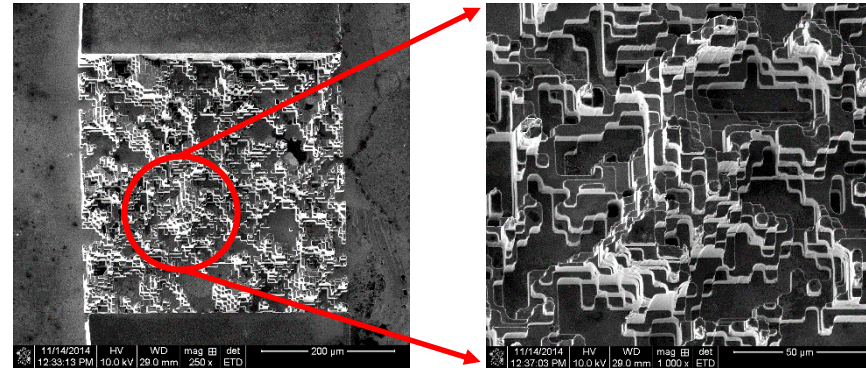
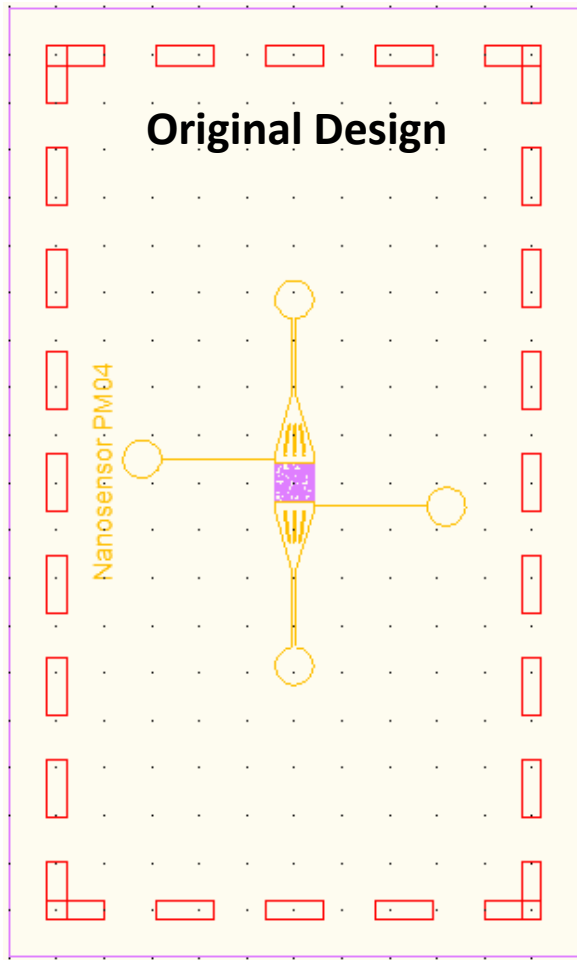


- Double-Sided Embossing
- Large-Area, Embossing with Complex Features
- 3D Bonded Micro-Chip Assemblies
- Integrated Alignment Features

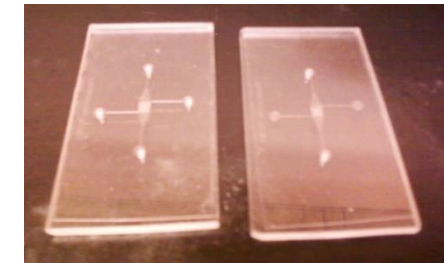
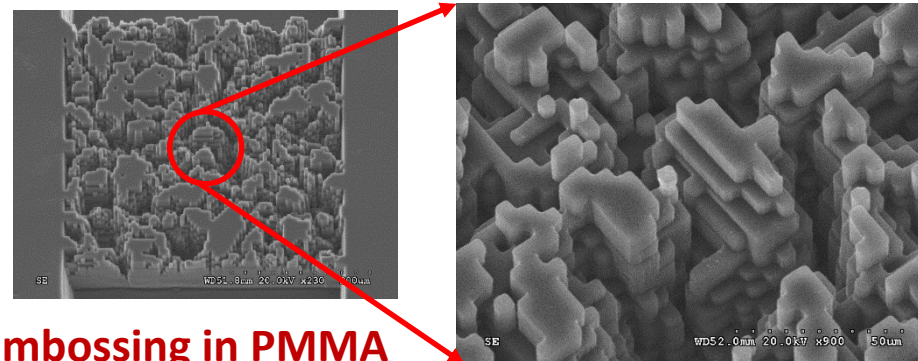




# High-Resolution, Multi-Layer PMMA Embossed Product



5- $\mu\text{m}$  features on plane,  
5- $\mu\text{m}$  depth resolution  
(13 layers) PMMA  
embossed and covered  
micro-chip



# Forming in Plastics Application

# Embossed Porous Media Micro-Model Experiments

## Objectives

The general strategic objectives of the rock-based micro-model experiments are to further the understanding of nanoparticle mobility phenomena in realistic, yet controlled, porous media geometries and to provide benchmark measurements for the validation of pore-scale flow and particle mobility models and codes.

### Tactical Objectives:

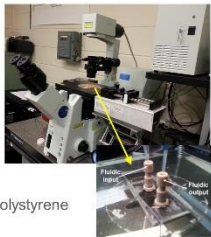
- Quantify particle velocity distributions in 3D and/or particle trajectories.
- Quantify particle number density distributions in 3D
- Quantify particle deposition/retention rates at appropriate locations
- Measure 3D micro-model geometry in situ
- Develop algorithms needed to achieve the above.

### The Intent is to:

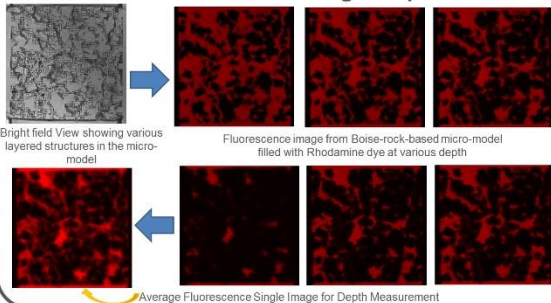
- Use the measurements to validate computational models of particle mobility including interactions of nano-particles with the micro-model walls (adsorption, deposition)
- Explore effects of particle characteristics (size, concentration), and flow rates
- Extend the experiments to application-specific particles, application-specific working fluids, and application-relevant micro-model materials (e.g. rock materials, clays, etc.).

## Some Experiment Details

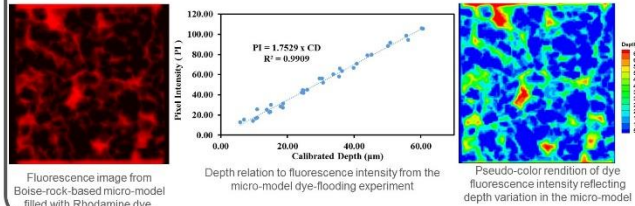
- Laser Scanning confocal microscope
- Blue laser (488 nm) excitation by Argon-ion Laser
- Photo-Multiplier Tube (PMT) recording
- Micro-model placed on inverted microscope stage
- Fixed volumetric flow rate of deionized water filtered by 0.1 μm filters driven using syringe pumps
- 10X, 40X air & fluid immersion objectives
- Fluorescent-labeled (absorb 488m, emit 612nm) polystyrene spherical particles with Ø300nm



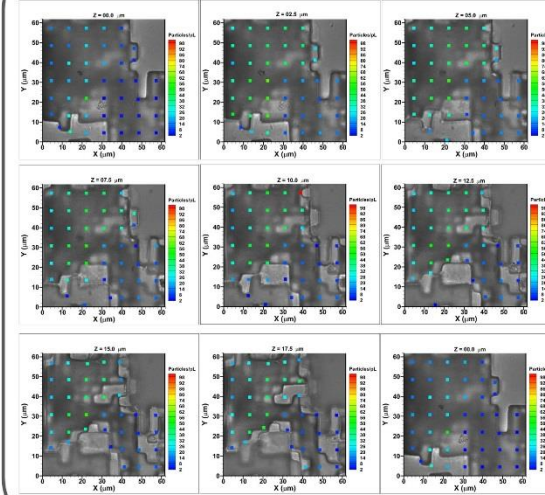
## In-Situ Fluorescence Image Acquisition



## In-Situ Micro-model Depth Measurement

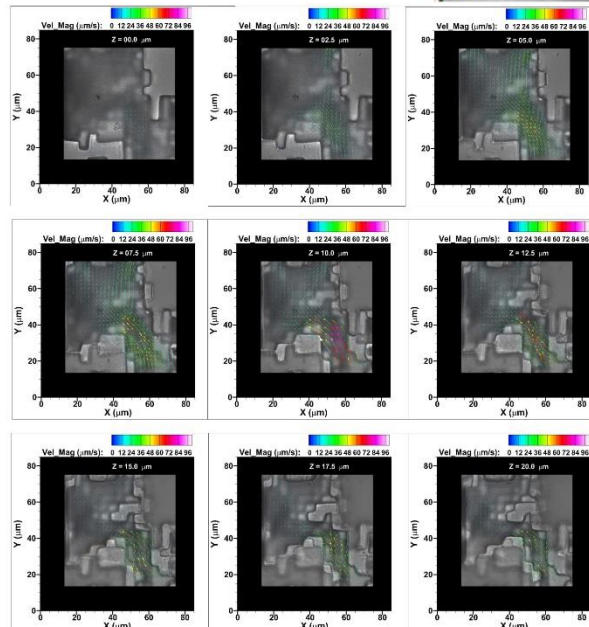
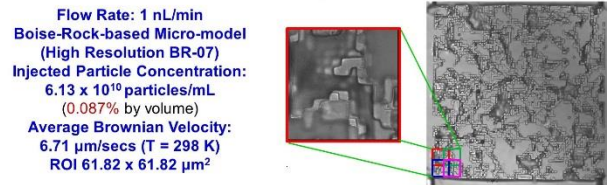


## 3D Particle Concentration Distributions



● Particle Counts at Various Depths

## 3D Particle Velocity Distributions



● Velocity distributions at Various Depths

## Summary

- Particle flow experiments were conducted in Boise-Rock-based high resolution micro-models.
- New algorithm was developed to measure depth in high resolution micro-models.
- 3D micro-model geometry was measured in situ from fluorescent dye-flooding.
- Particle velocity distributions along fast moving region were measured in 3D.
- Particle number distributions were measured in 3D at high resolution.
- 3D micro-model geometry was measured in situ from fluorescent dye-flooding.
- Future Works
  - Experimental protocol and perform experiment with AEC-developed particles in high resolution as well as real rock based micro-models.

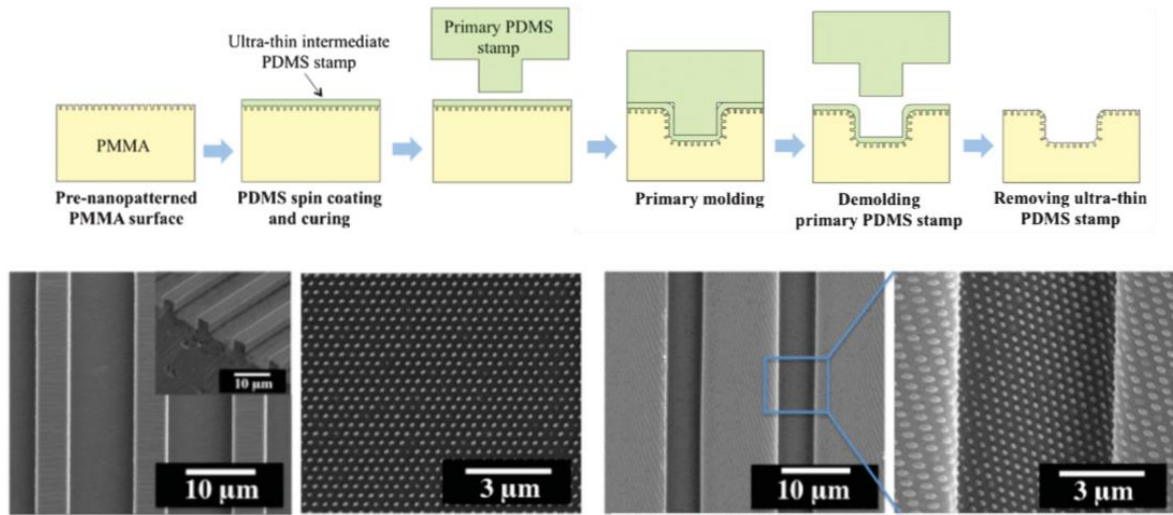


## Acknowledgements

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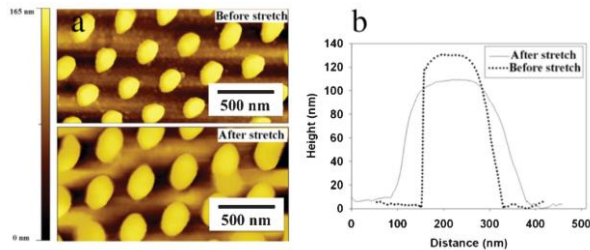
# 3D Nano-Scale Replication (Forming / Embossing)

## Two-level 3D Nano-molding

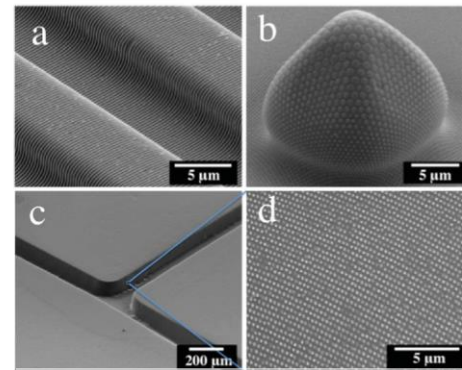


Original Primary Stamp (Left) and Nano-Patterned PMMA Surface (Right)

Final Nano-Patterned Microchannels

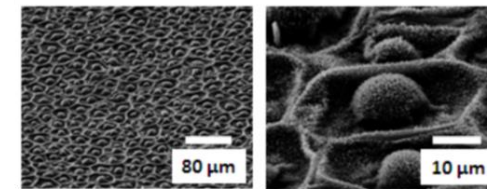
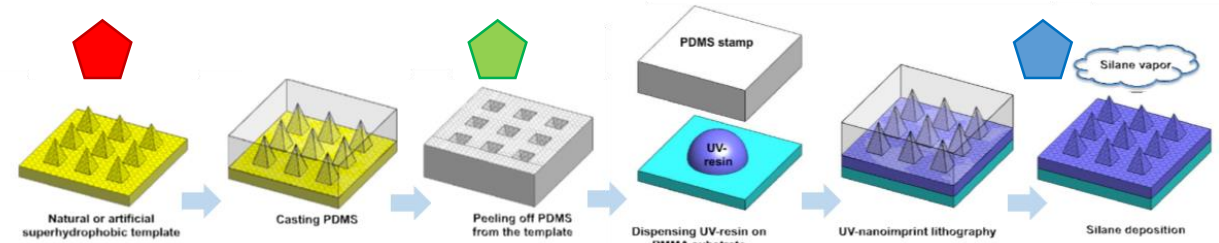


Size of the Replicated Nano-Scale Features via AFM

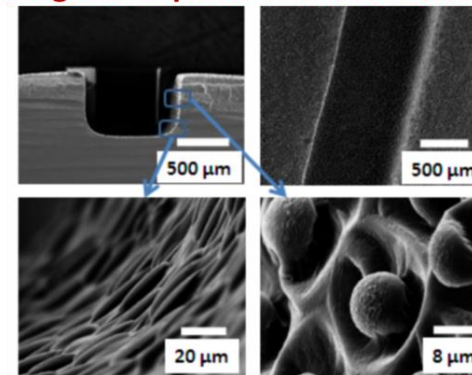


Various Replicated 3D Nano-Patterned Surfaces

## Replication-based Superhydrophobic Surface Fabrication Through Soft UV-Nanoimprint Lithography and Silane Deposition

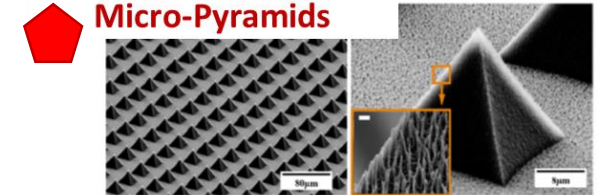


Original Elephant-Ear Leaf Pattern

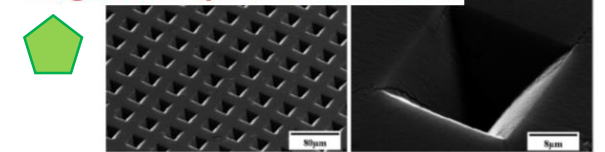


3D Elephant-Ear Leaf Surface Structure on Microchannel Walls

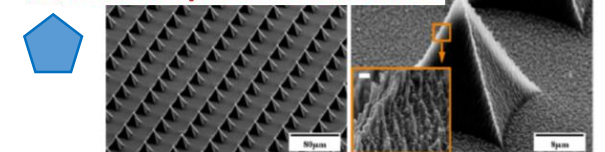
Original Nano-Patterned Micro-Pyramids



Negative Replica of Structure



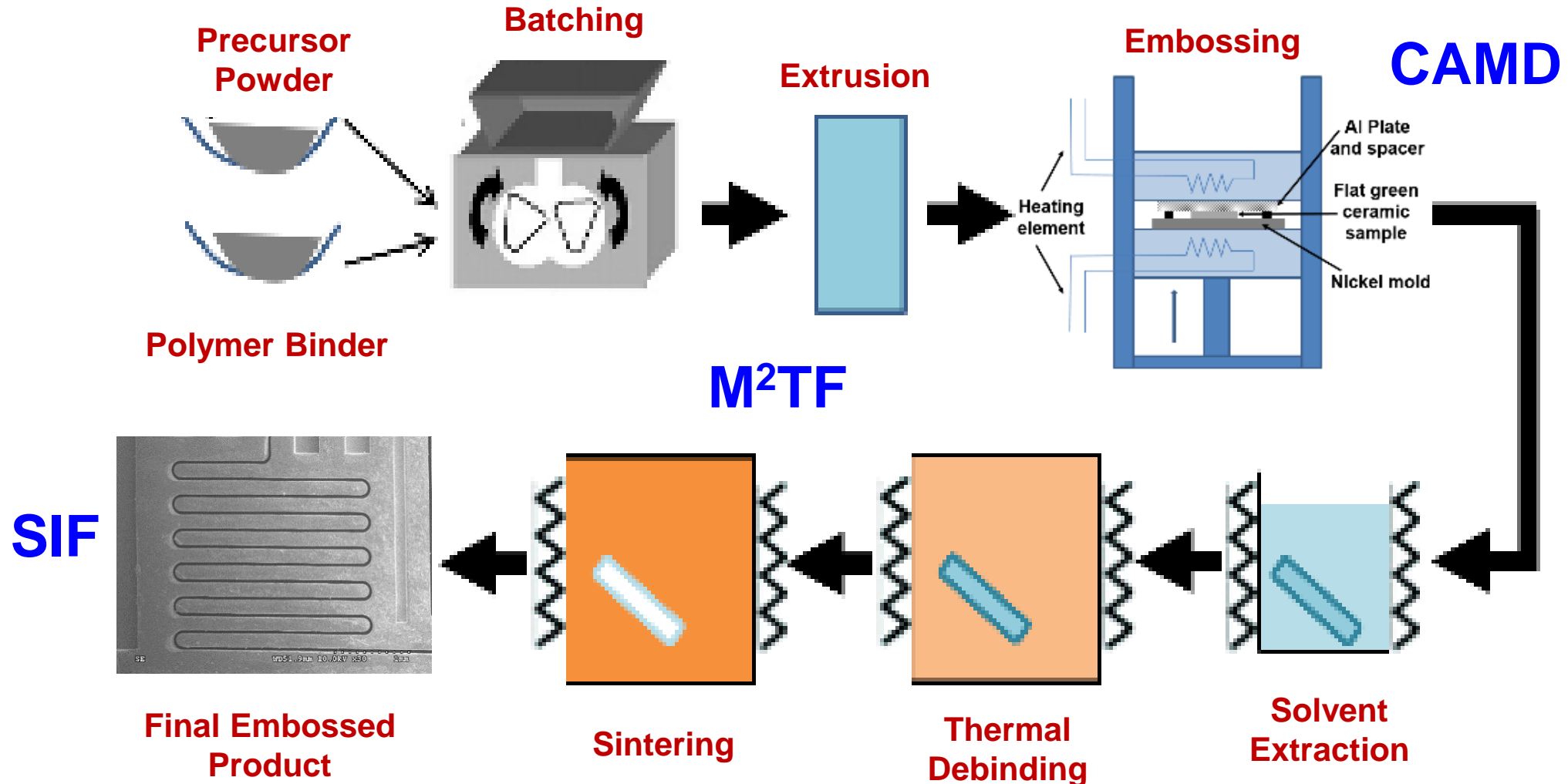
Positive Replica of Structure



Replication-based Forming (Embossing) Micro/Mezo-Fabrication

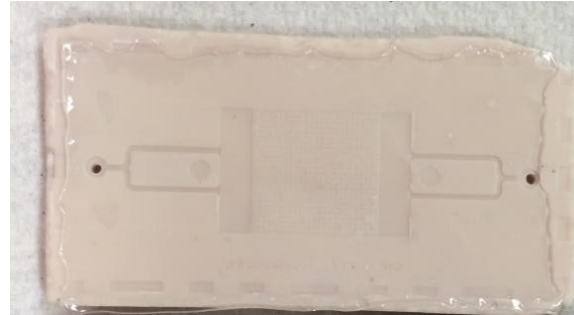
# Example Outcomes in Ceramics

# Ceramic Synthesis and Forming Process

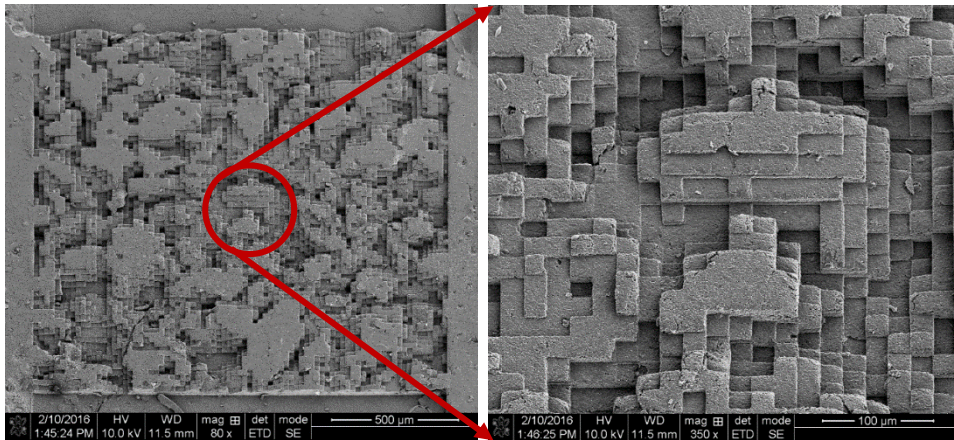


# Multi-Layer Embossed Ceramic Product

Ceramic embossed and covered micro-chip

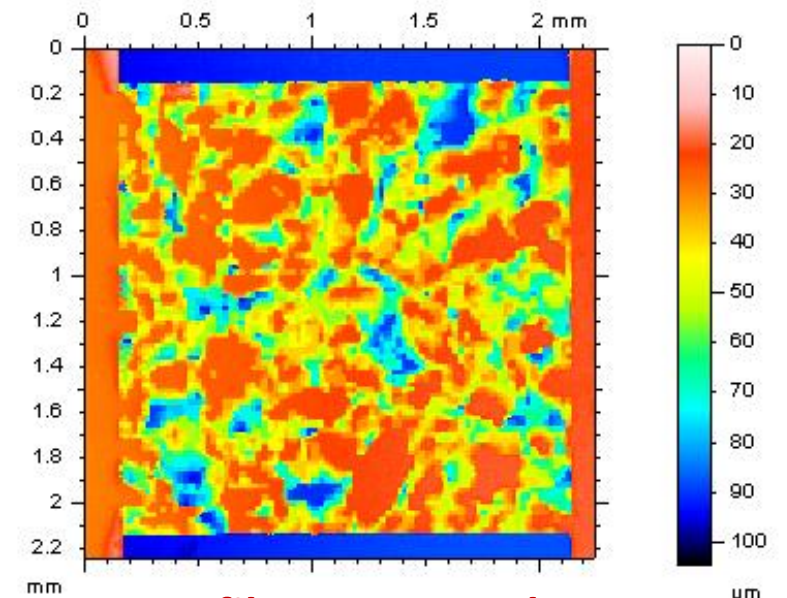
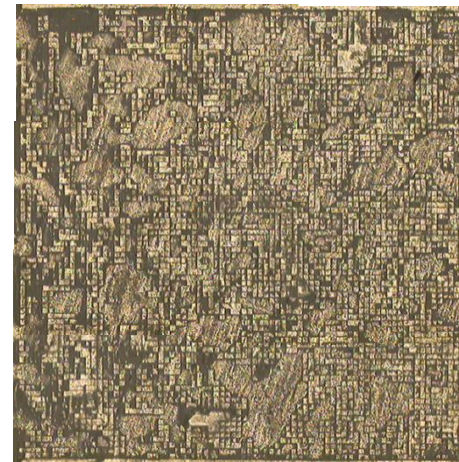


25- $\mu\text{m}$  feature on plane,  
5- $\mu\text{m}$  depth resolution  
13 layers



Overall view

Detail



Profilometry result