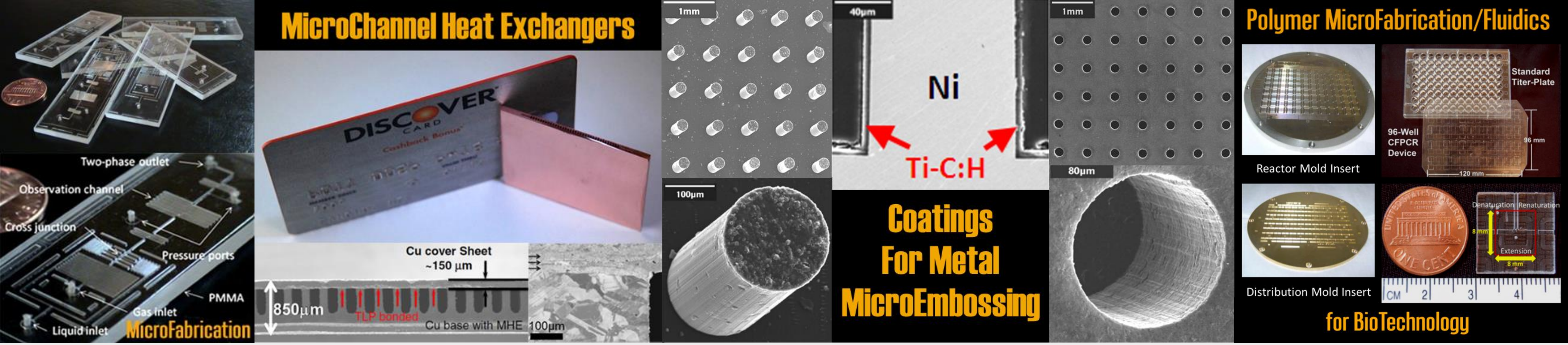
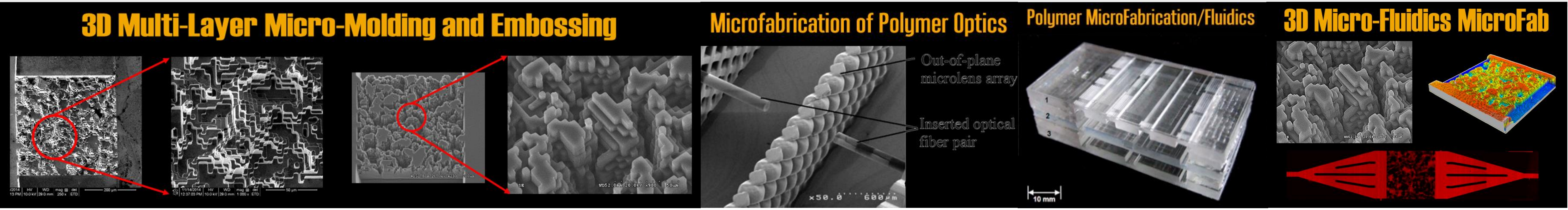
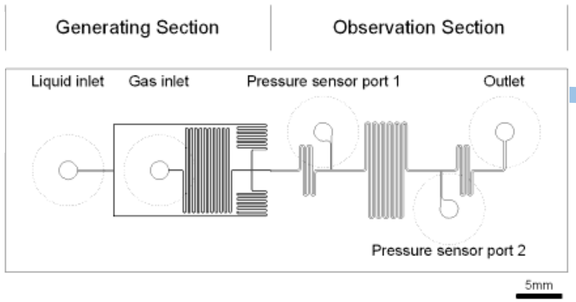


Replication-based Forming (Embossing) Fabrication/Manufacturing Methods Overview



College of
Engineering
Department of
Mechanical & Industrial Engineering

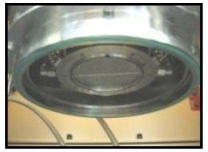
Micro-Milling and Forming (Embossing) Process

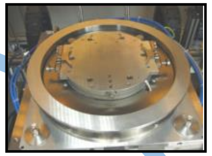


Design

AM^{2}F

Micro-milling of mold inserts



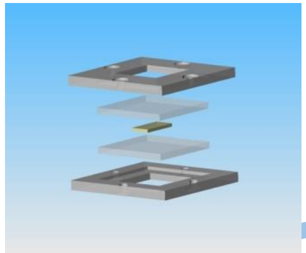


CAMD

Hot-embossing

Embossed Polymer plates
(PMMA, PC, COC)

Metrology
Cutting, drilling
and cleaning



M^{2}TF

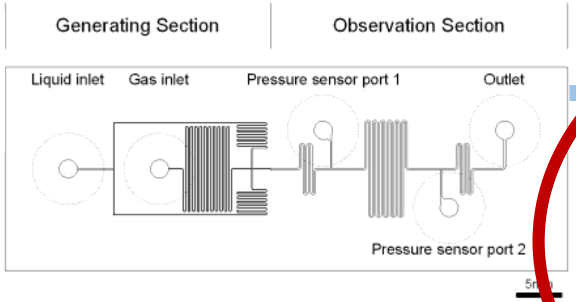
Thermal fusion bonding

Polymer chips

College of Engineering
Department of Mechanical & Industrial Engineering

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

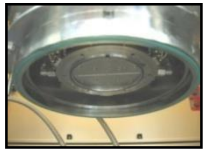
Micro-Milling and Forming (Embossing) Process

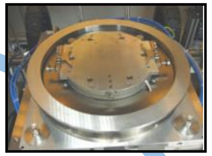


Design

AM^{2}F

Micro-milling of mold inserts



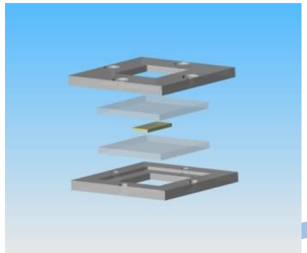


CAMD

Hot-embossing

Embossed Polymer plates
(PMMA, PC, COC)

Metrology
Cutting, drilling
and cleaning



M^{2}TF

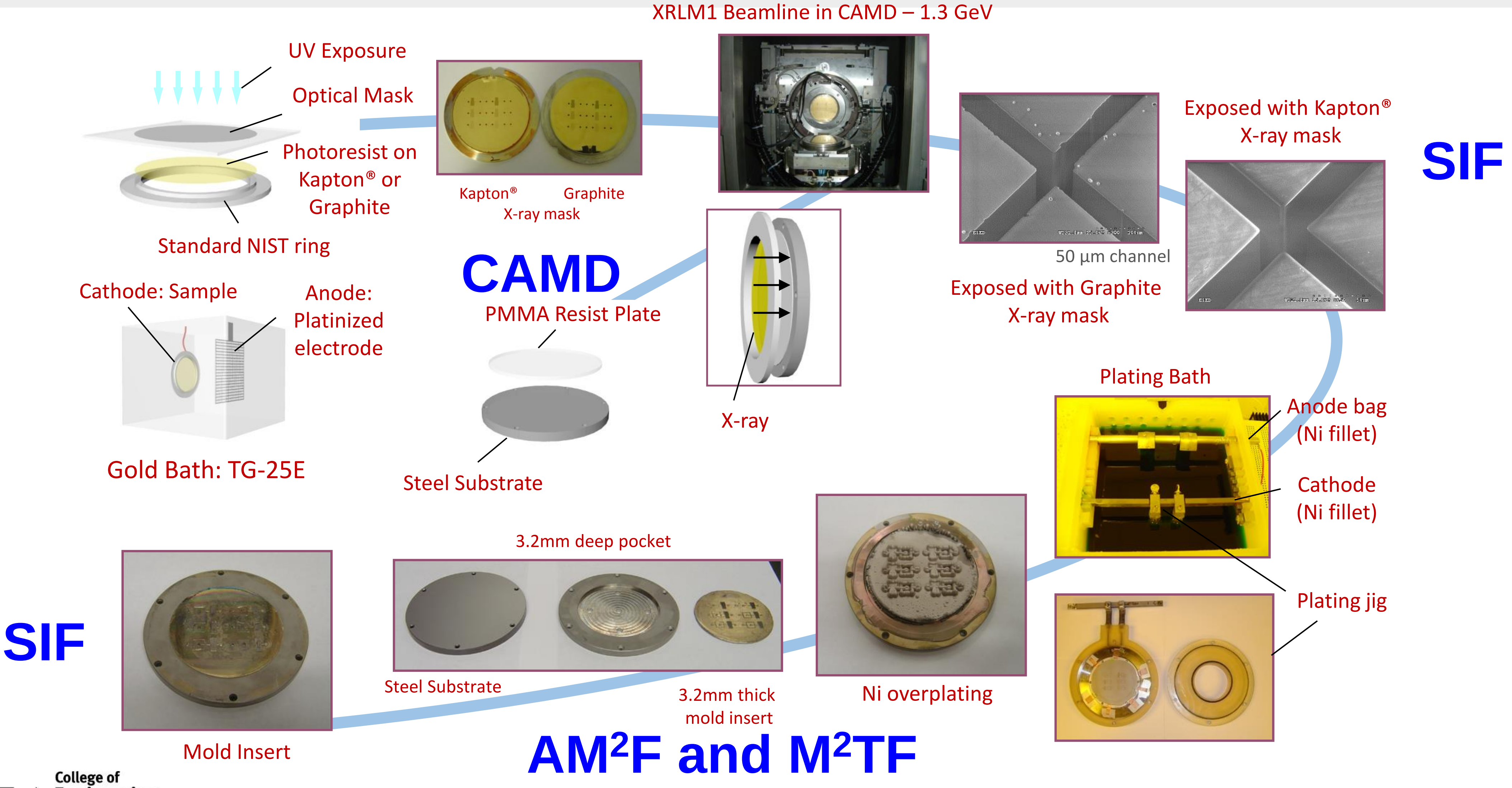
Thermal fusion bonding

Polymer chips

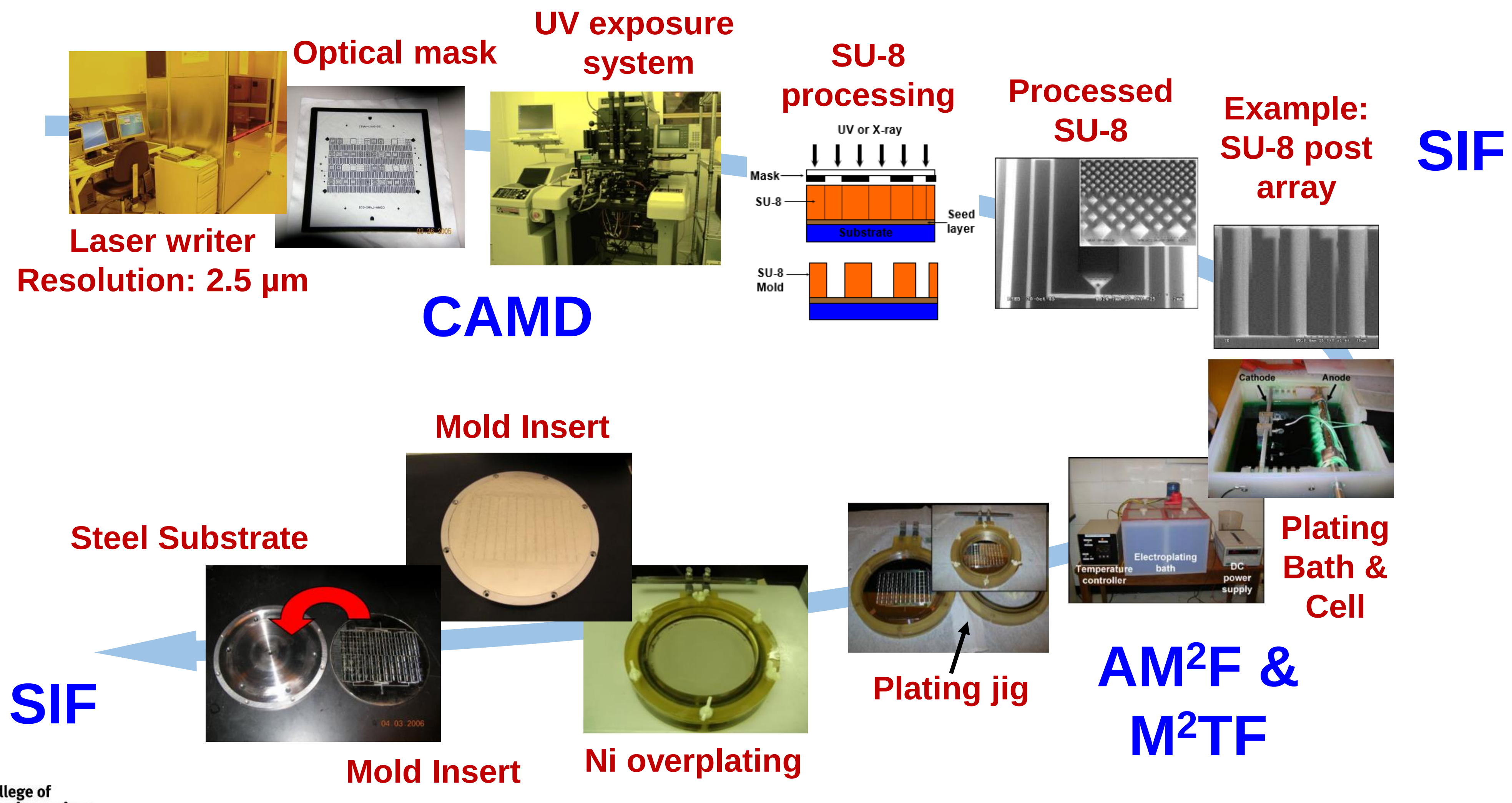
LSU College of Engineering
Department of
Mechanical & Industrial Engineering

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

Mold Insert Fabrication: LiGA Process (X-Ray)

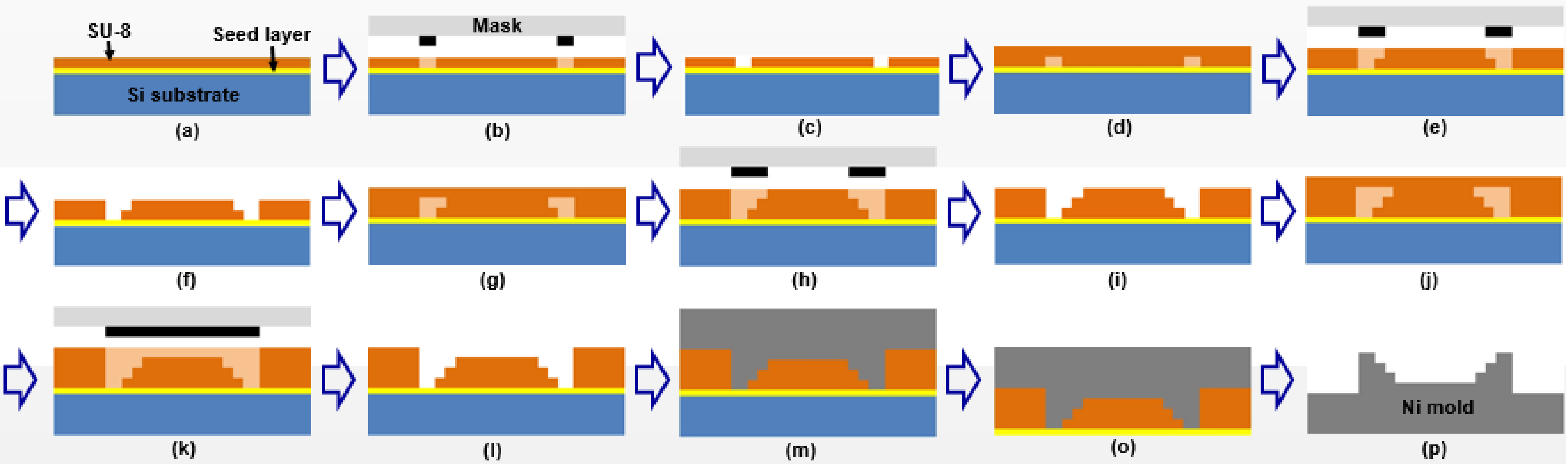


Mold Insert Fabrication: LiGA Process (UV in SU-8)



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-µm

LSU College of Engineering
Department of Mechanical & Industrial Engineering

Daniel Park, Dimitris E. Nikitopoulos

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

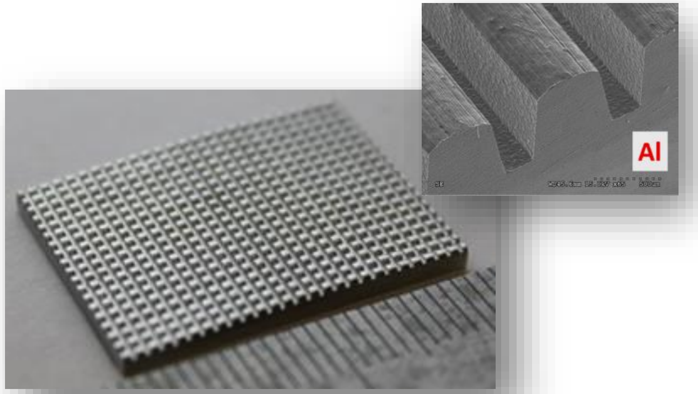
Example Outcomes in Metals

CIMM

CIMM: Multi-Scale Metal Forming

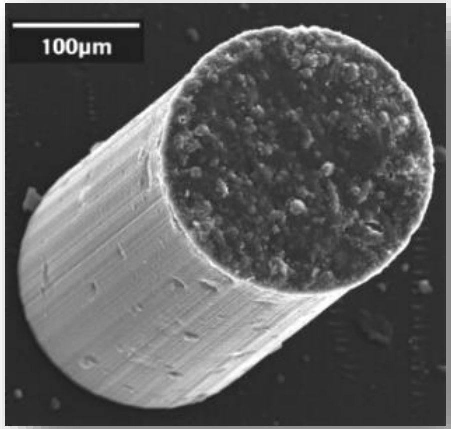
Coatings and Interfaces

Replication-Based Manufacturing

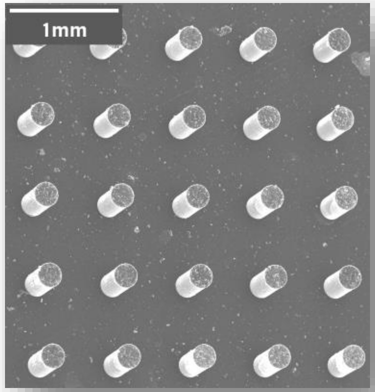


Thin-Film Coatings for Mold Inserts

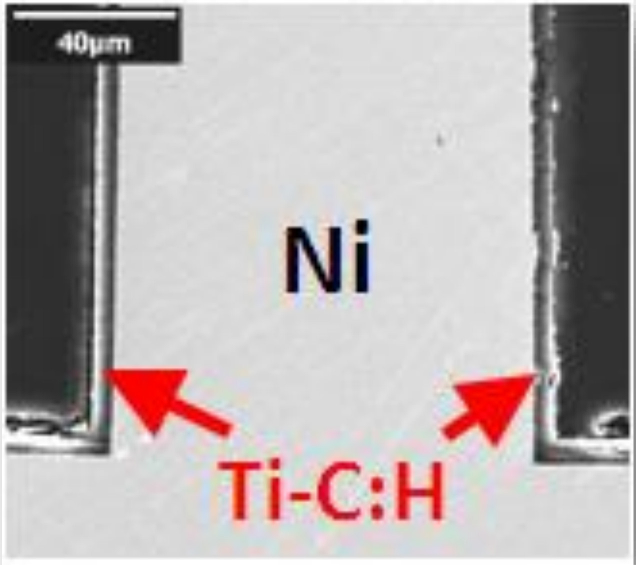
Hard, low-friction coatings through Inductively coupled plasma (ICP) assisted PVD.



Ni micro-post mold insert

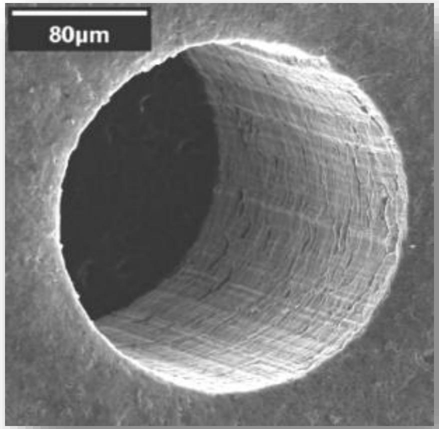


Coating: Enabling Technology

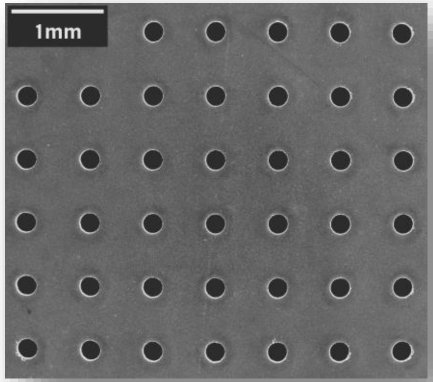


M^2TF

Wenjin Meng's Group



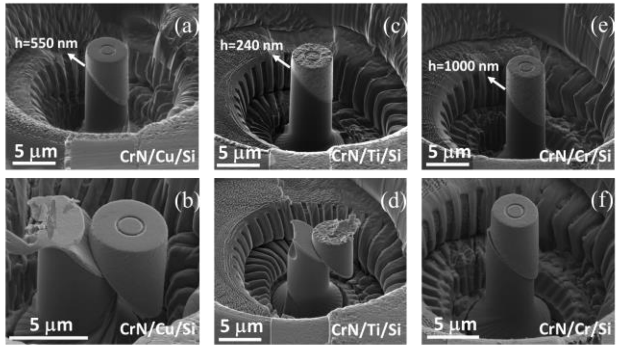
Micro-hole array in Al



Solid/Solid Interfacial Mechanical Integrity

Measure & Understand Interfacial Strength & Failure

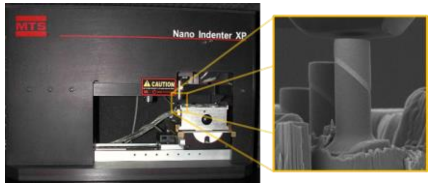
ICME Approach

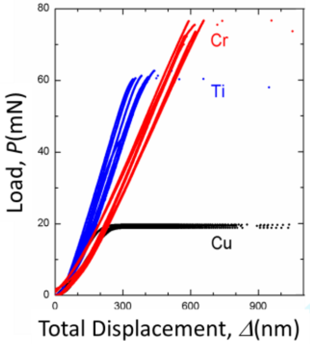


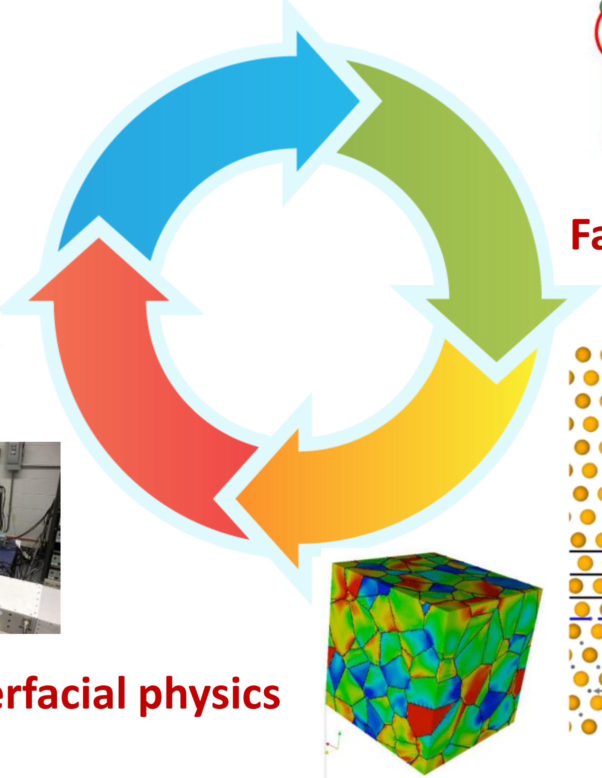
Axial Compression Test

Diamond punch on FIB milled post

SIF

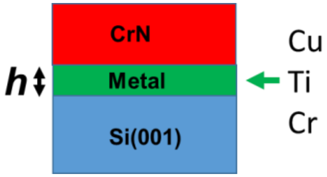


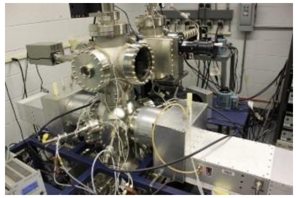




Interface Synthesis

M²TF



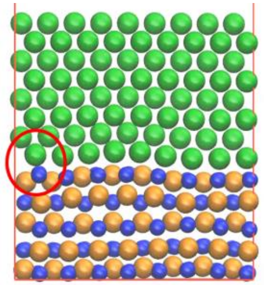


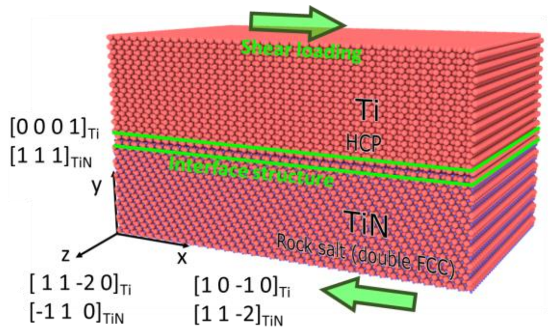
Development of continuum models with interfacial physics

MD Simulations and Dislocation Dynamics

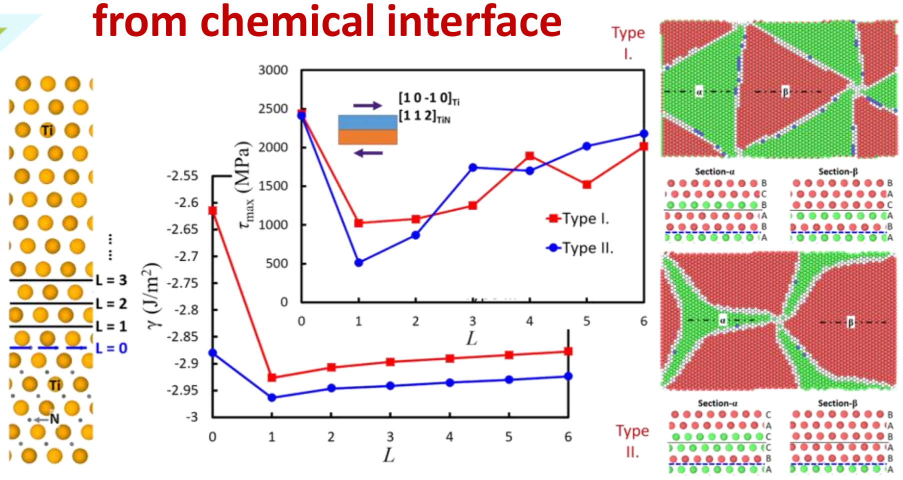
Edge dislocation "unlocks" interface

HPC, Loni



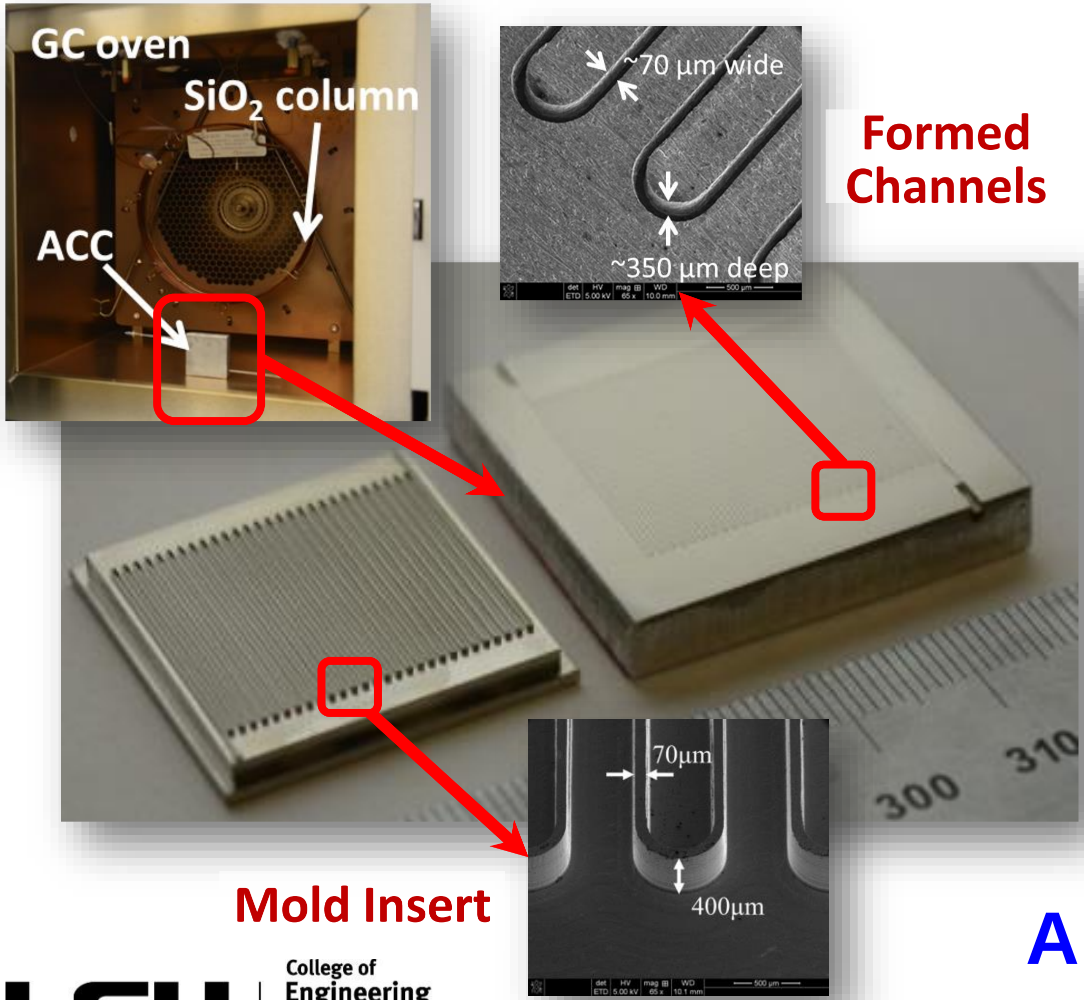


Failure at one atomic level away from chemical interface



Metal Micro-Forming (Embossing)

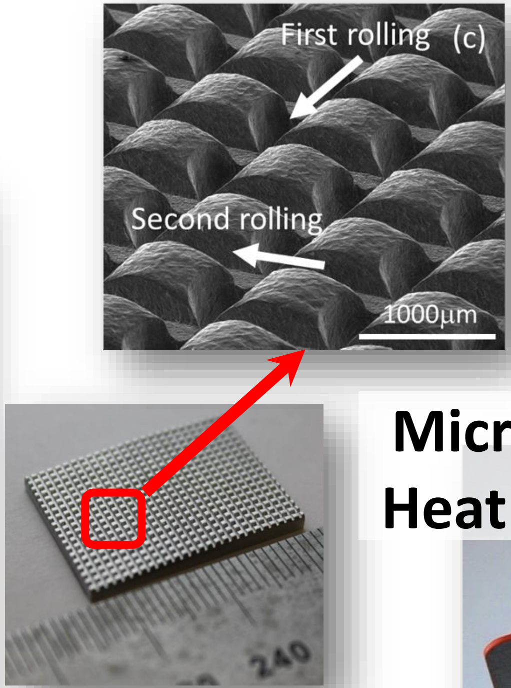
Gas-Chromatograph Chip in Aluminum (ACC)

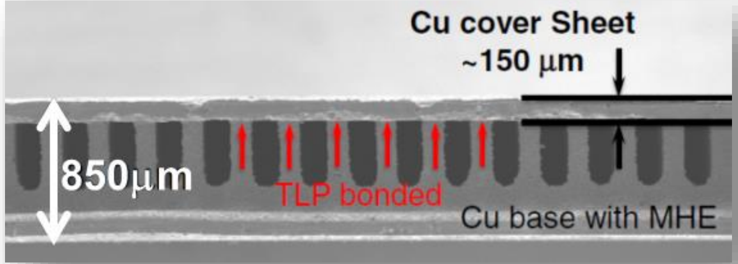


Formed Channels

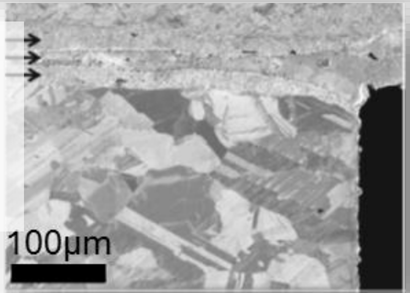
Mold Insert

Textured Metal Surfaces





Transient Liquid Phase (TLP) bonded cover



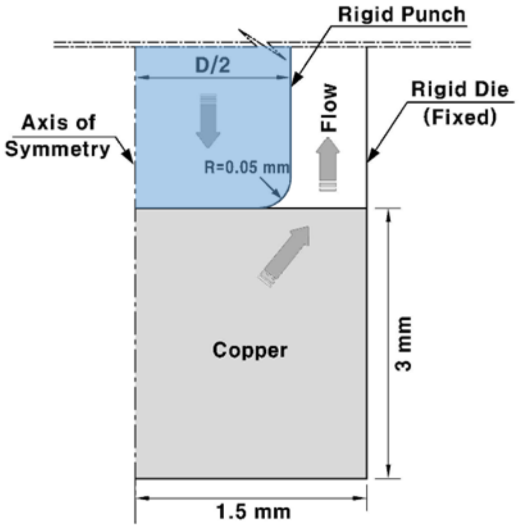
Micro-Channel Heat Exchanger

AM²F & M²TF

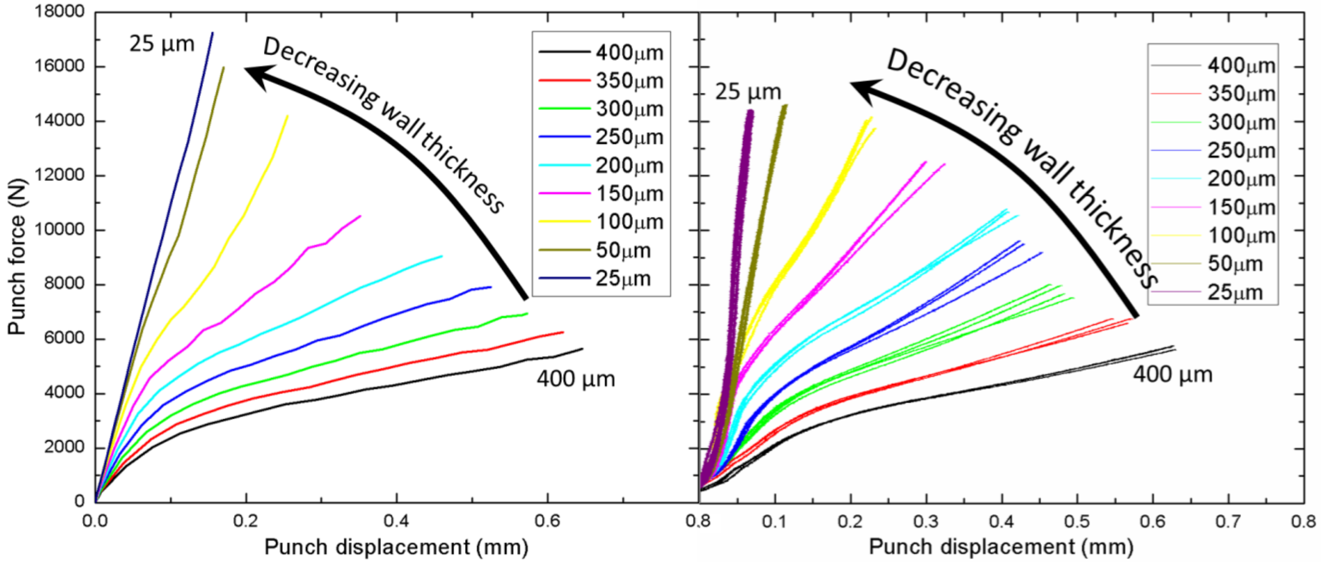
Wenjin Meng's Group

Micro-Scale Reverse Extrusion

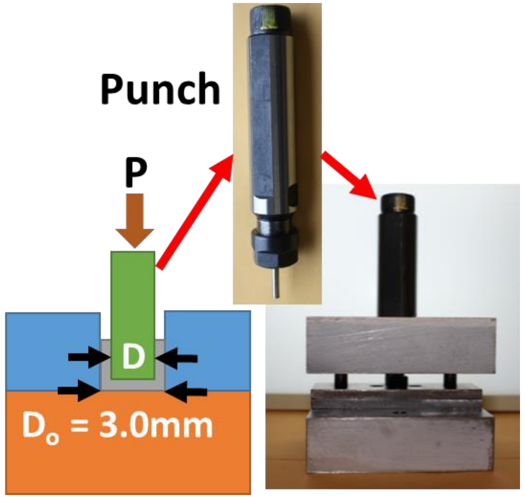
FEA Domain



Continuum Plasticity FEA Simulation Result ~ Experimental Result

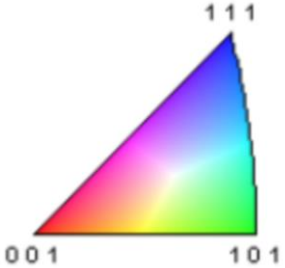


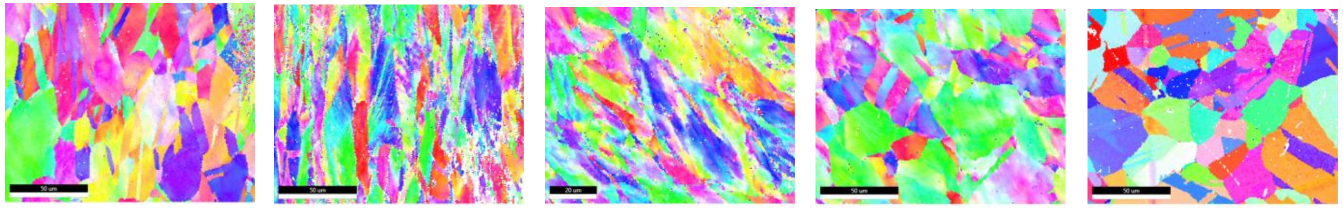
Reverse Extrusion Experiment



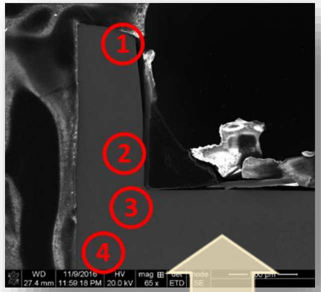
Top view of extruded sample

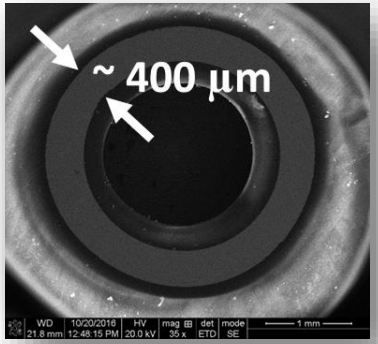
Associated Electron BackScatter Diffraction (EBSD) maps





Area 1 Area 2 Area 3 Area 4 Annealed

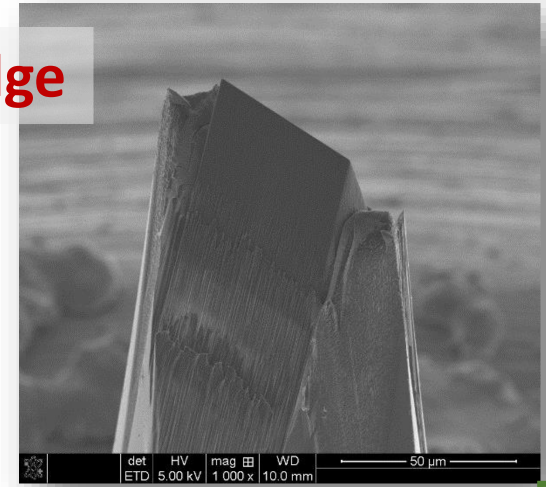




SEM image of transverse cross-section of extruded Cu samples

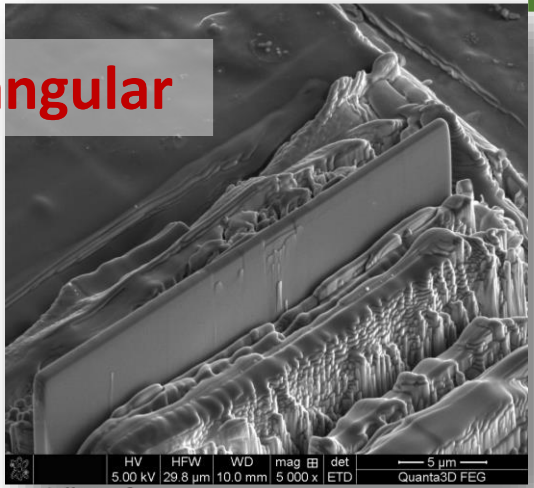
Nano-Scale Replication (Forming / Embossing)

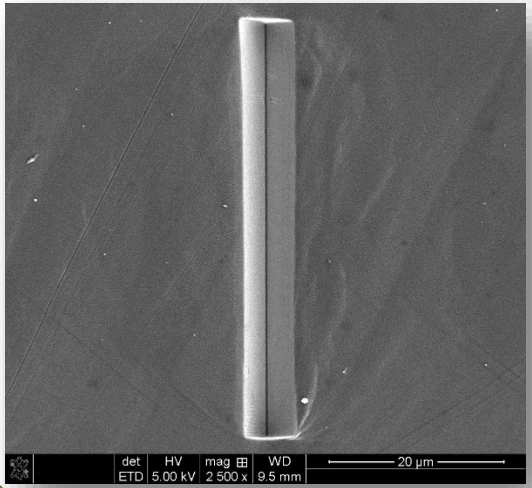
Wedge



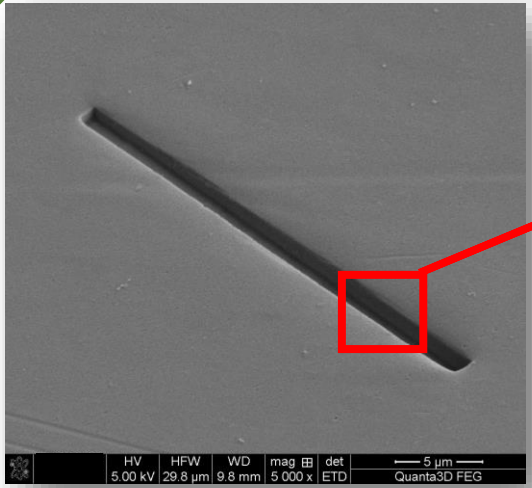
FIB Milled Diamond Tools

Rectangular

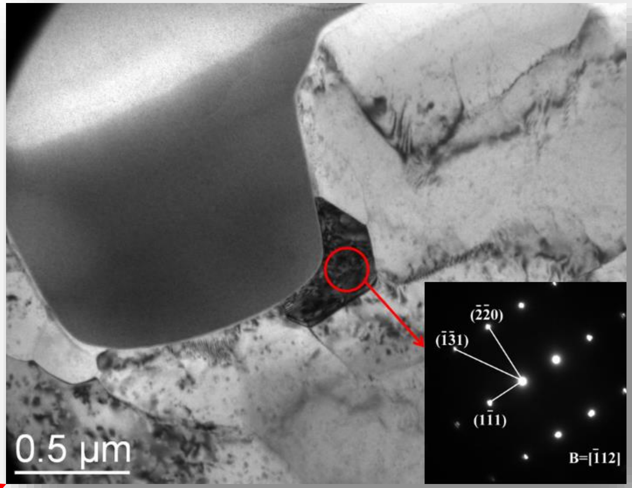




Nano-Embossings in Aluminum



Material structure underneath imprint



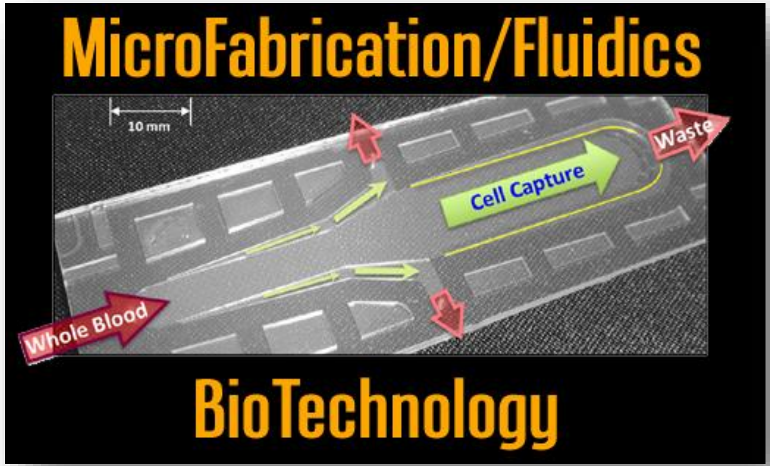
TEM

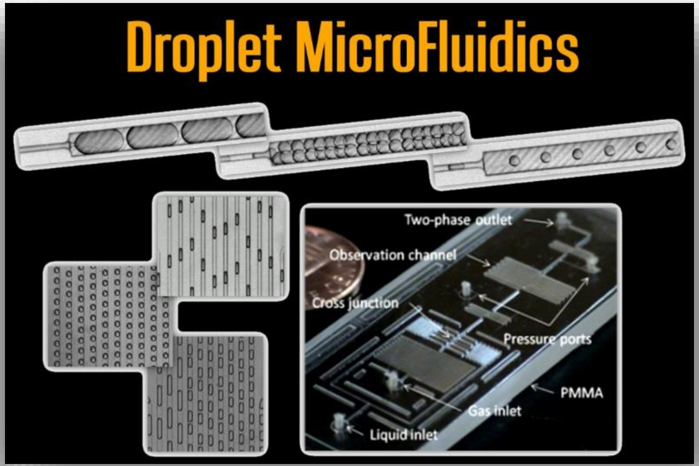
Wenjin Meng's Group

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

Example Outcomes in Polymers

Polymer Products for Applications



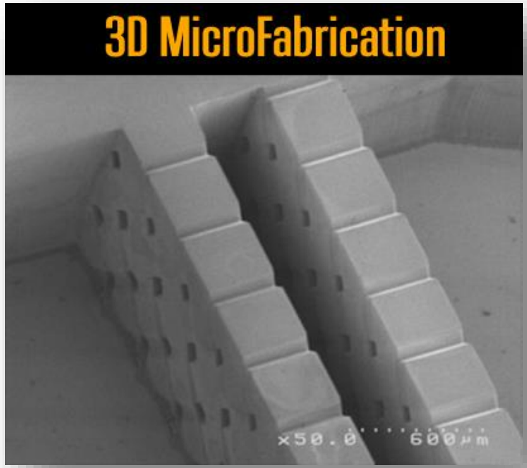


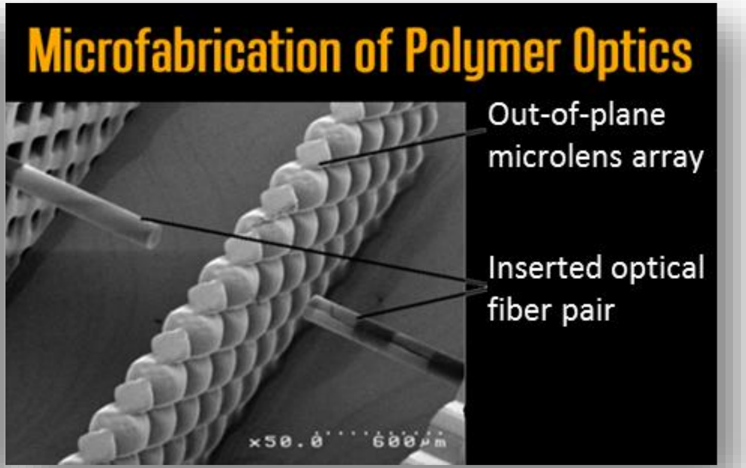
Single-layer embossed products in PMMA and PC for BioTechnology applications (features down to 25 µm)

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

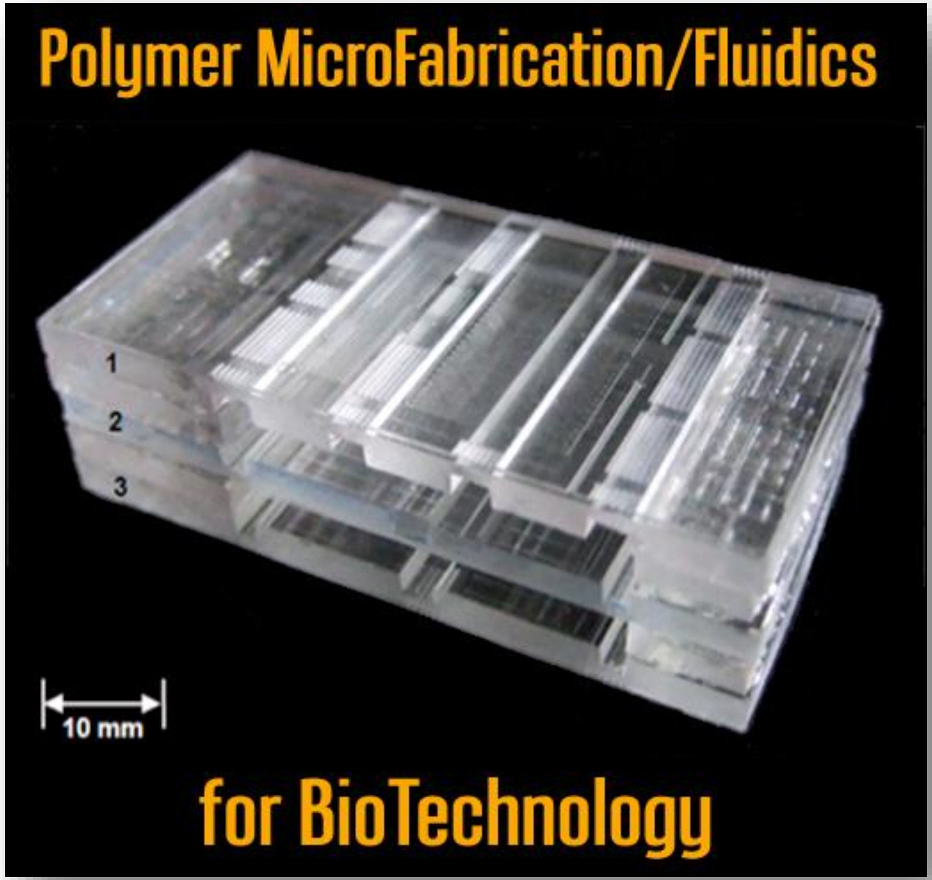
3D products in SU-8 by means of UV lithography for BioTechnology applications (features down to 75 µm)

Wanjun Wang's Group

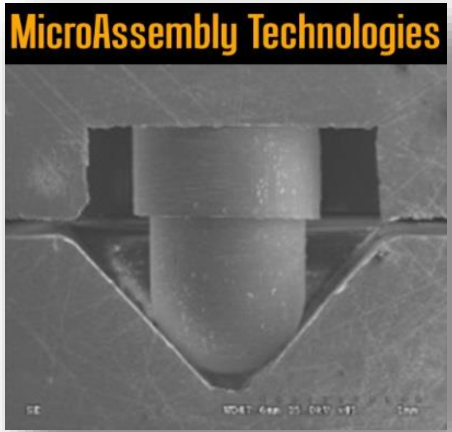


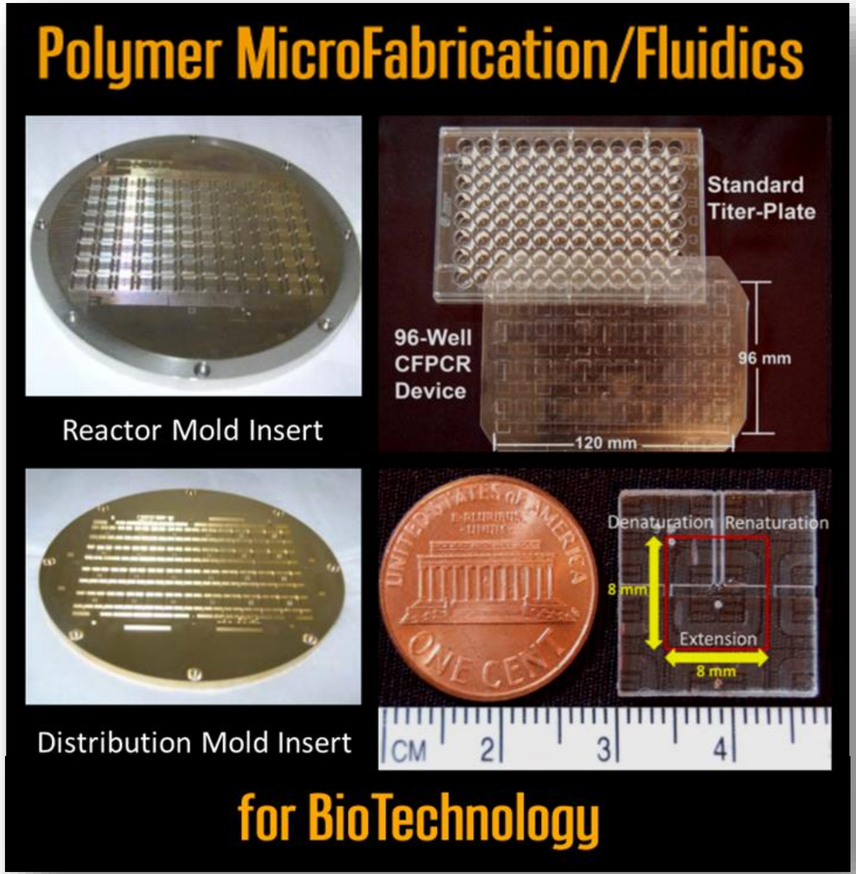


Complex Embossed Assembled Products for Applications



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

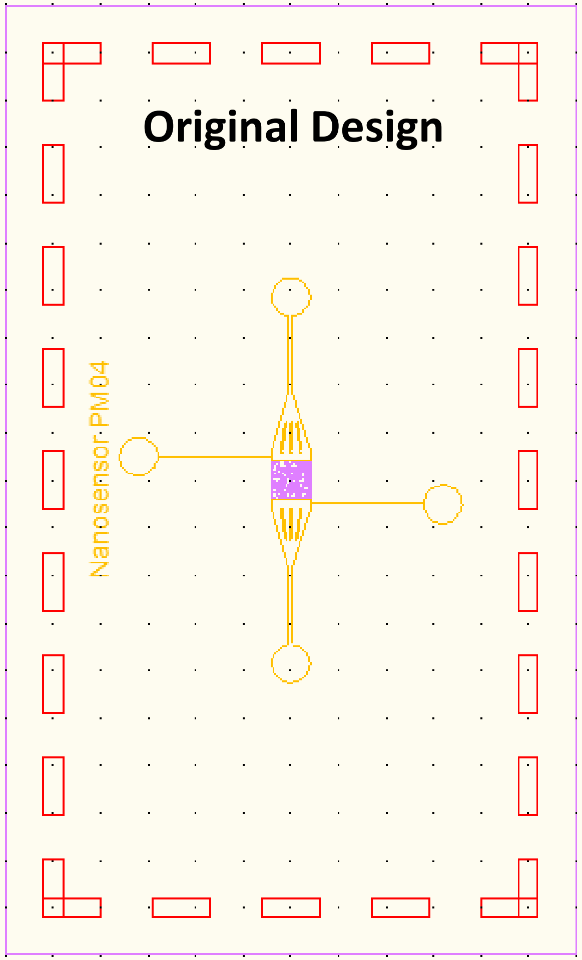


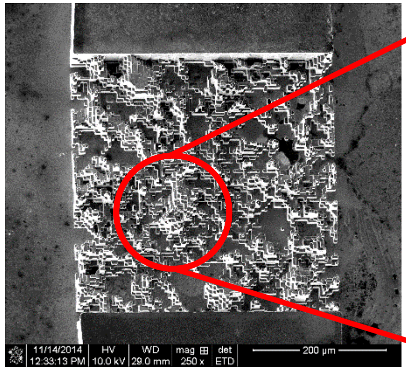


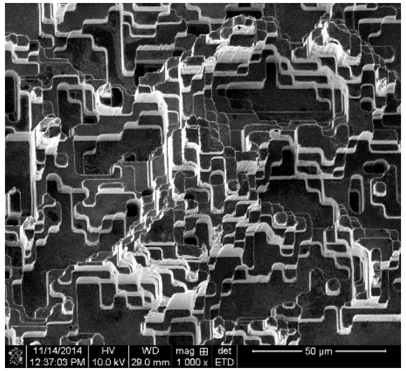
LSU College of Engineering
Department of Mechanical & Industrial Engineering

D. Park, M. C. Murphy, D. E. Nikitopoulos

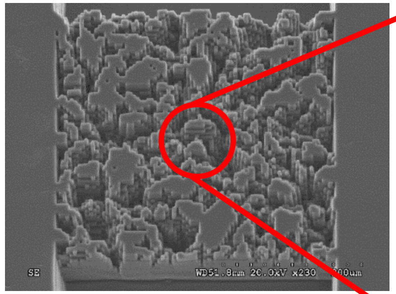
High-Resolution, Multi-Layer PMMA Embossed Product

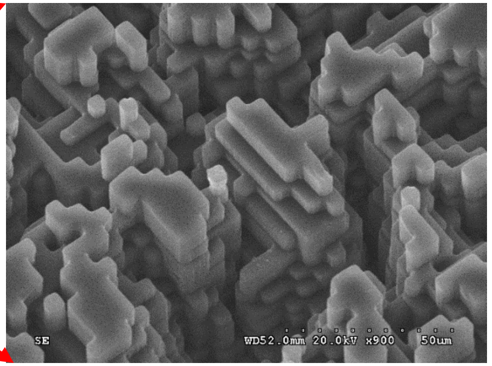






13-Ni-layer mold insert with 5 µm features



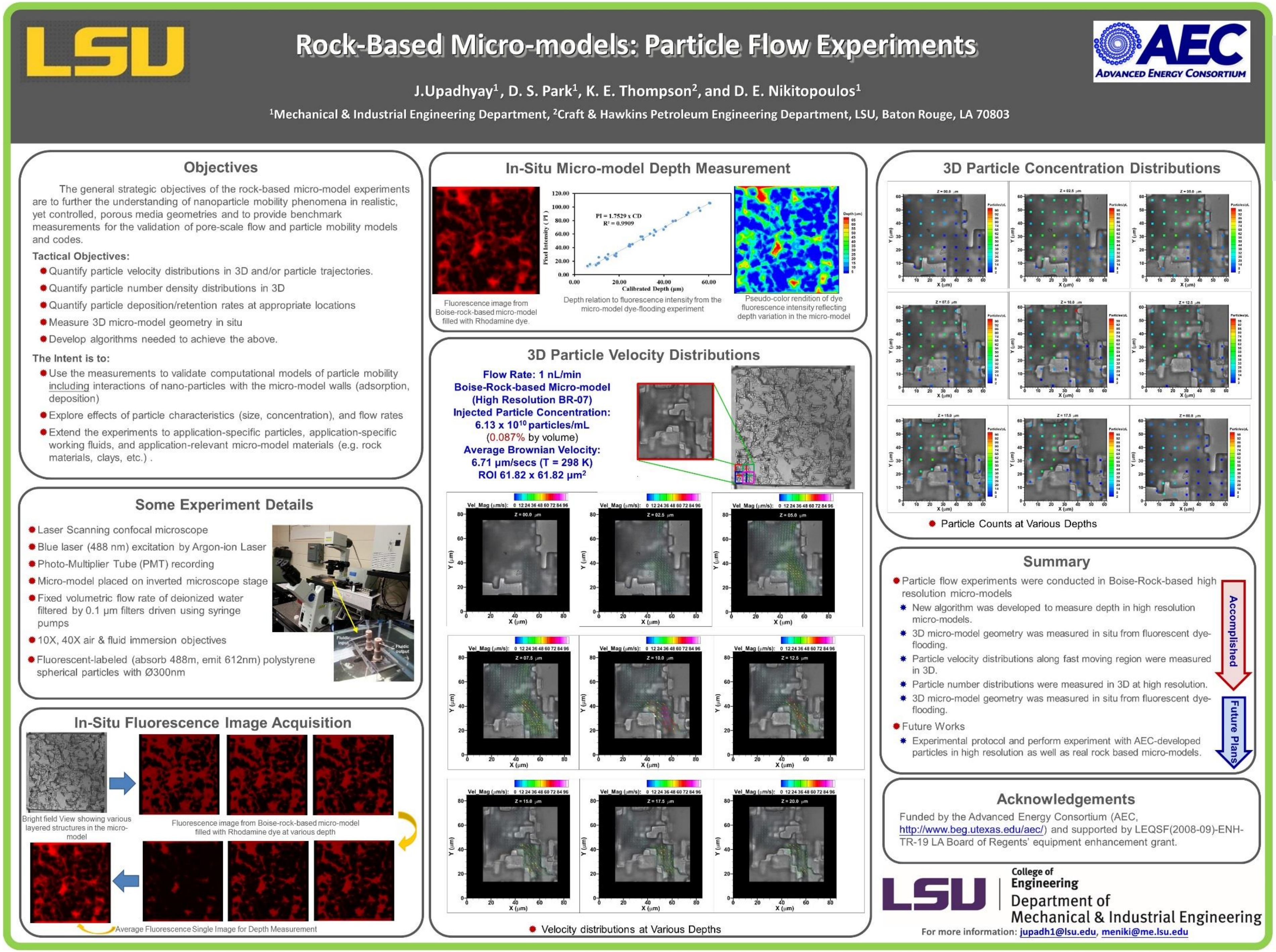


Embossing in PMMA

5-µm features on plane, 5-µm depth resolution (13 layers) PMMA embossed and covered micro-chip

LSU College of Engineering
Department of Mechanical & Industrial Engineering

Daniel Park, Dimitris E. Nikitopoulos



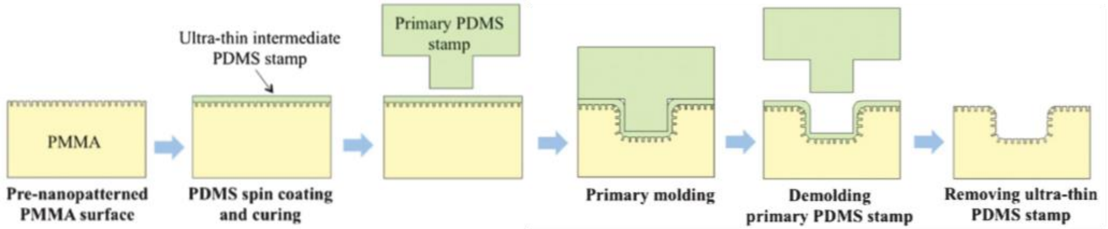
Forming in Plastics Application

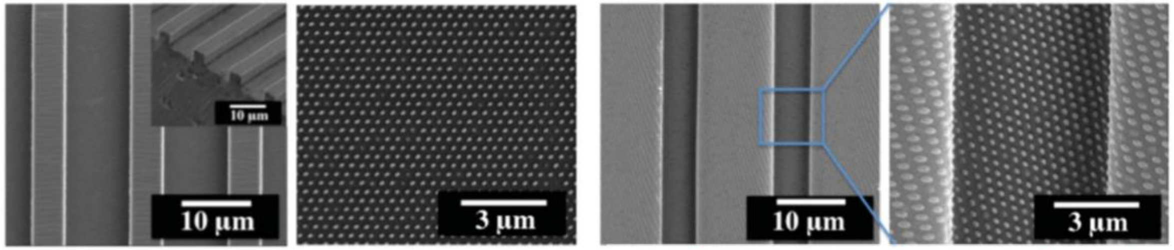
Embossed Porous Media Micro-Model Experiments

LSU College of Engineering
Department of Mechanical & Industrial Engineering

3D Nano-Scale Replication (Forming / Embossing)

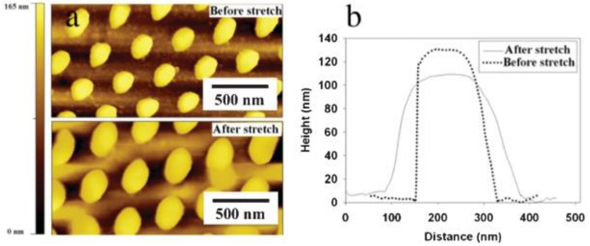
Two-level 3D Nano-molding



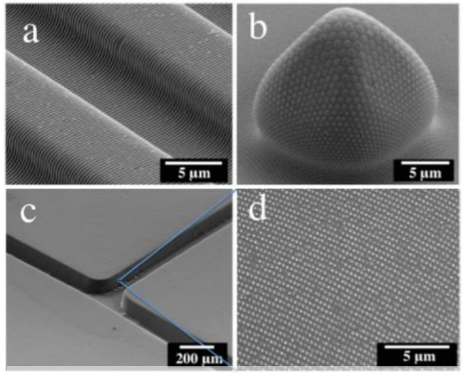


Original Primary Stamp (Left) and Nano-Patterned PMMA Surface (Right)

Final Nano-Patterned Microchannels

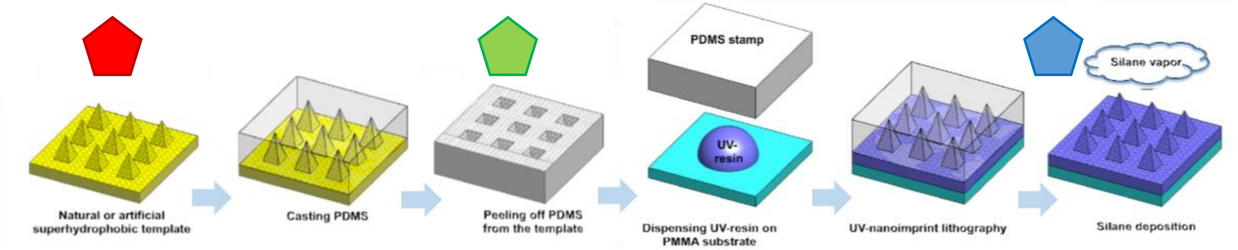


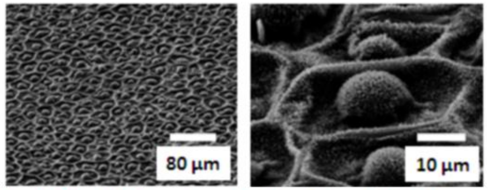
Size of the Replicated Nano-Scale Features via AFM



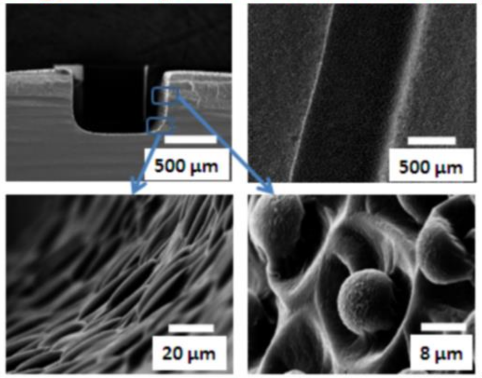
Various Replicated 3D Nano-Patterned Surfaces

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



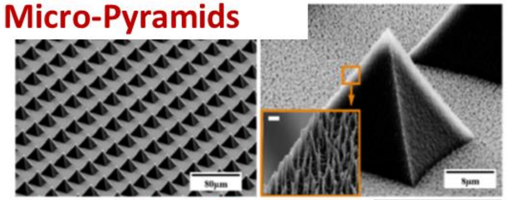


Original Elephant-Ear Leaf Pattern

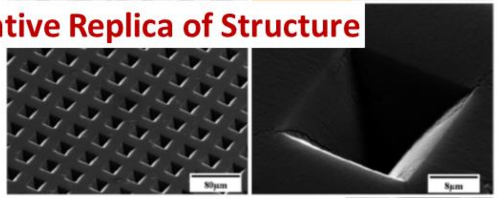


3D Elephant-Ear Leaf Surface Structure on Microchannel Walls

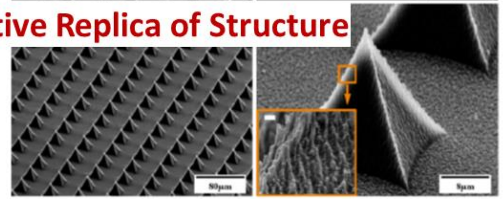
Original Nano-Patterned Micro-Pyramids



Negative Replica of Structure



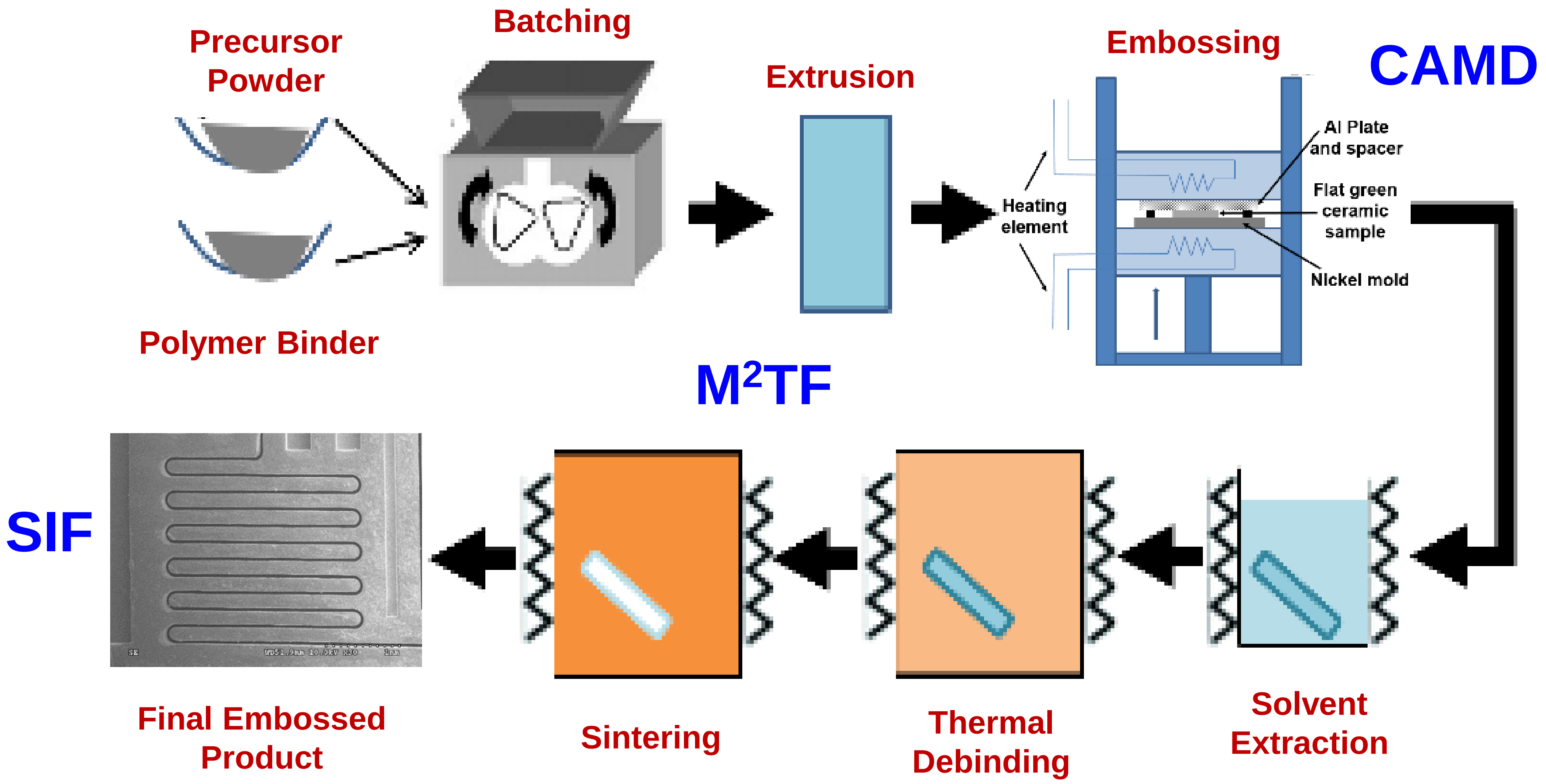
Positive Replica of Structure



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

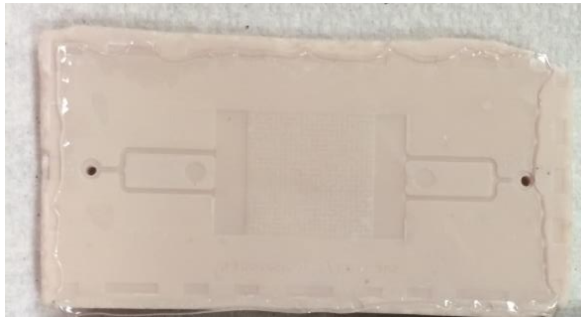
Example Outcomes in Ceramics

Ceramic Synthesis and Forming Process

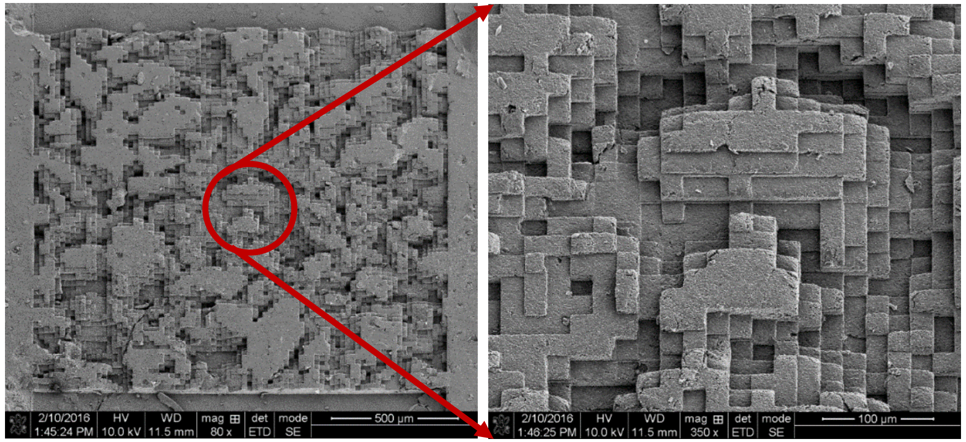


Multi-Layer Embossed Ceramic Product

Ceramic embossed and covered micro-chip

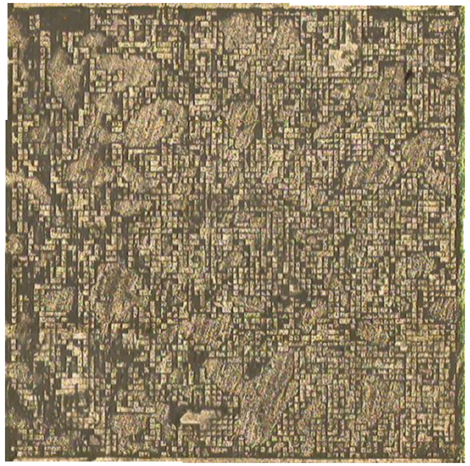


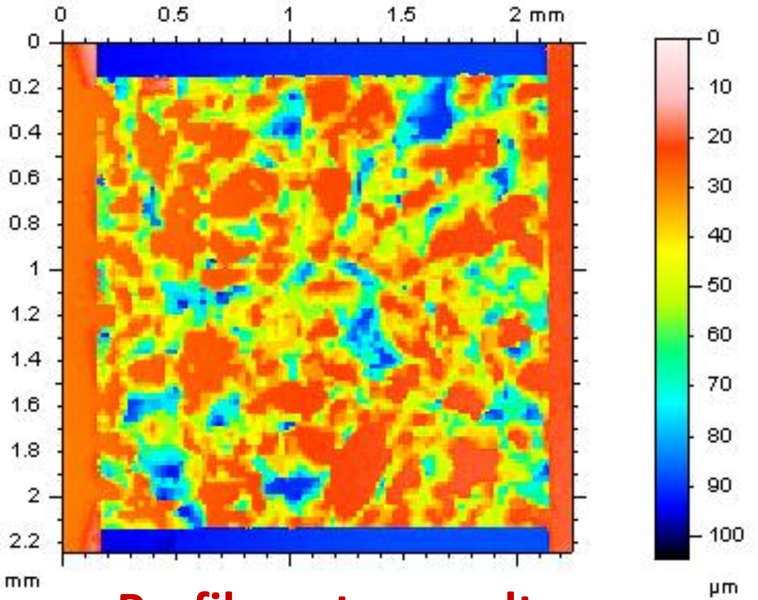
25-µm feature on plane,
5-µm depth resolution
13 layers



Overall view

Detail





Profilometry result

Daniel Park, Ingmar Schoegl, Dimitris E. Nikitopoulos