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**
- Design

**Generating Section**
- Generating Section
  - Liquid inlet
  - Gas inlet
  - Pressure sensor port 1
  - Cutlet
  - Pressure sensor port 2

**Observation Section**

**AM²F**
- Micro-milling of mold inserts

**CAMD**
- Hot-embossing

**M²TF**
- Metrology
  - Cutting, drilling and cleaning

**Polymer chips**
- Polymer chips

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

**Thermal fusion bonding**
- Thermal fusion bonding

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Micro-Milling and Forming (Embossing) Process

Design

Micro-milling of mold inserts

Polymer chips

Thermal fusion bonding

AM²F

Hot-embossing

M²TF

Embossed Polymer plates (PMMA, PC, COC)

Metrology
Cutting, drilling and cleaning

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Mold Insert Fabrication: LiGA Process (X-Ray)

- UV Exposure
- Optical Mask
- Photoresist on Kapton® or Graphite
- Standard NIST ring
- CAMD
- PMMA Resist Plate
- X-ray
- Steel Substrate
- XRLM1 Beamline in CAMD – 1.3 GeV

Exposed with Graphite X-ray mask
Exposed with Kapton® X-ray mask

- 50 μm channel

- Gold Bath: TG-25E
- Anode: Platinized electrode
- Cathode: Sample

- Exposed with Graphite X-ray mask

- Plating Bath
- Anode bag (Ni fillet)
- Cathode (Ni fillet)
- Plating jig

- 3.2mm deep pocket
- 3.2mm thick mold insert

- AM²F and M²TF

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

Optical mask
UV exposure system
SU-8 processing
Processed SU-8
Example: SU-8 post array

Laser writer
Resolution: 2.5 µm

CAMD

Steel Substrate
Mold Insert

SIF

Mold Insert
Ni overplating

Plating jig

AM²F & M²TF

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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

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

Example Outcomes in Metals
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.

Coating: Enabling Technology

Ni micro-post mold insert

Micro-hole array in Al

M^2TF

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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

SIF

MD Simulations and Dislocation Dynamics

HPC, Loni

Edge dislocation “unlocks” interface

Failure at one atomic level away from chemical interface

Wenjin Meng & Shuai Shao Groups
Metal Micro-Forming (Embossing)

Gas-Chromatograph Chip in Aluminum (ACC)

Transmittant Liquid Phase (TLP) bonded cover

Formed Channels

Textured Metal Surfaces

Micro-Channel Heat Exchanger

AM²F & M²TF

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Micro-Scale Reverse Extrusion

FEA Domain

Reverse Extrusion Experiment

Continuum Plasticity FEA Simulation Result ~ Experimental Result

Associated Electron BackScatter Diffraction (EBSD) maps

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

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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 \( \mu m \))

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

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Complex Embossed Assembled Products for Applications

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

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High-Resolution, Multi-Layer PMMA Embossed Product

13-Ni-layer mold insert with 5 µm features

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

Embossing in PMMA

Daniel Park, Dimitris E. Nikitopoulos
Rock-Based Micro-models: Particle Flow Experiments

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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 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 volume flow rate of dieoktenized water filtered by 0.1 μm filter driven using syringe pumps
- 10X, 40X oil & fluid immersion objectives
- Fluorescent-labelled (absorb 488nm, emit 612nm) polystyrene spherical particles with Ø300nm

In-Situ Fluorescence Image Acquisition

3D Particle Concentration Distributions

Flow Rate: 1 mL/min
Boise-Rock-based Micro-model (High Resolution BS-07)
Injected Particle Concentration: 6.12×1010 particles/cm³ (0.007% by volume)

Average Brownian Velocity: 6.71 μm/s (T = 298 K)
R25 61.82 ± 0.82 μm²/s

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 dyeing.
- 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 dyeing.
- Future Works

Experimental protocols performed experiment with AEC-developed particles in high resolution as well as real rock-based micro-models.

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Embosed Porous Media
Micro-Model Experiments
3D Nano-Scale Replication (Forming / Embossing)

Two-level 3D Nano-molding

- Ultra-thin intermediate PDMS stamp
- Primary PDMS stamp
- Primary molding
- Demolding primary PDMS stamp
- Removing ultra-thin PDMS stamp

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

- Natural or artificial superhydrophobic template
- Coating PDMS
- Popping off PDMS from the template
- Dispensing UV resin on PDMS substrate
- UV-nanoimprint lithography
- Silane deposition

Original Nano-Patterned Micro-Pyramids

Size of the Replicated Nano-Scale Features via AFM

Various Replicated 3D Nano-Patterned Surfaces

Original Elephant-Ear Leaf Pattern

Negative Replica of Structure

Positive Replica of Structure

Sunggook Park’s Group

LSU
College of Engineering
Department of Mechanical & Industrial Engineering
Replication-based Forming (Embossing) Micro/Mezo-Fabrication

Example Outcomes in Ceramics
Ceramic Synthesis and Forming Process

1. Precursor Powder
2. Polymer Binder
3. Batching
4. Extrusion
5. Embossing
6. M^2TF
7. SIF
8. Final Embossed Product
9. Sintering
10. Thermal Debinding
11. Solvent Extraction
12. CAMD

Ingmar Schoegl’s Group, D. E. Nikitopoulos’ Group
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

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