Self Assembly of Micro and Nano Systems

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Outline

• Integrated actuation, alignment, and latching for 3D MEMS

• Templated assembly by selective removal
  – Concept
  – Experiments
  – Model comparison
Assembly: Creating Complex Systems from Simple Parts

- Assembly is a broad field
- Focus of our work: assembly for 3D MEMS and assembly of complex systems of micro and nanocomponents
- Topic 1: Integrated actuation, alignment, and latching to create 3D MEMS from sets of hinged 2D precursors (in collaboration with Barbastathis group)
- Topic 2: Templated assembly by selective removal (shape- and size-selective assembly of micro and nanocomponents from fluid into designated sites on a surface)
Actuation, Alignment, and Latching of 3D MEMS

- Starting materials: 2D precursors, connected by microfabricated hinges
- Various forms of actuation, including Lorentz force
- As flaps are actuated, cascaded alignment mechanism engages to bring components into proper alignment
- Triangular protrusions engage into rhombic holes; centering of protrusions in holes aligns flaps
- Applications: optical materials and devices, hybrid microsystems
Alignment Mechanism

- Cascaded alignment begins at aligning features that are closest to the hinge
  - Lowest alignment precision
  - Easiest to engage features
- Fine alignment takes place in features that are furthest from the hinge
  - Highest alignment precision
  - Most difficult to engage features
- Combines precision of fine alignment with the ease of coarse alignment through the automatic engagement of subsequent aligning features
Assembly results

- Implemented in SU-8 with Au hinges and Lorentz actuation
- Successful corner cube assembly; aligned from 11° out of correct position to within 1°
- Continuing research on measurement and improvement of assembly precision
Templated Assembly by Selective Removal (TASR)

- Unlike hinged assembly shown previously, TASR enables the simultaneous assembly of fully-separated micro and nanocomponents from a fluid bath onto a surface.
- Placement of components on the surface is selective based on the components’ sizes and shapes.
- Useful when components of different shapes and sizes are needed for different functions in system.
- Applications for chromatography and nanomanufacturing.
Key Elements of TASR

1. Chemical functionalization promotes component-surface adhesion in fluid

2. Binding sites are holes in the surface – stronger binding in holes that match a component’s size and shape

3. Controlled mechanical forces to remove poorly-matched components from incorrect sites
Experimental Overview

- Assembly in a fluid medium
- For these experiments, templates are etched silicon chips, and components are silica spheres (2 \(\mu\)m and 636 nm in diameter)
- Competition between adhesion and removal effects drives selectivity
Adhesion

• Surface phenomenon
• Template patterned to match components’ shapes and coated with SAMs to make them hydrophobic
• Spherical components
  → hemispherical holes in template
• Strength of adhesion dependent on content of water in assembly fluid as well as shape match
Mechanical Forces

- Assembly fluid excited by ultrasonic beam at 1.7 MHz
- Ultrasound stirs assembly fluid for circulation
- Ultrasound applies forces to components (added mass, viscous, drag, Basset, etc.)
- Forces attempt to remove components from substrate
- Balance between adhesion and mechanical forces determines assembly
Experiment: Template Fabrication

1. Grow 1.7 μm of oxide
2. Spin 125 nm of PMMA and bake
3. E-beam to expose PATTERN 1
4. BOE etch to form small holes
5. Piranha clean to remove PMMA
6. Spin 125 nm of PMMA and bake
7. E-beam to expose PATTERN 2
8. BOE etch to form large holes
9. Piranha clean to remove PMMA
10. Spin 125 nm of PMMA and bake

Silicon
Silicon oxide
PMMA
Assembly Templates

Profile of a small hole (measured by AFM) with some distortion from ideal hemispherical shape.
Experiments: Assembly Setup

- Different assembly fluid compositions:
  4%, 8%, and 12% water in acetone (to vary strength of adhesion forces)

- Different input voltages to transducer:
  50V – 100V (to vary strength of mechanical forces)
Characterization

- Optical microscopy

Yield definition

\[
Yield = \frac{\# \text{ of holes filled with components}}{\text{total \# of holes}}
\]
Typical Yield vs. Transducer Input Voltage

- Maximum yield in matching sites ~ 97%
- Yield in non-matching sites < 10%
- Process is selective!

- ▲ 636 nm spheres in matching holes
- ■ 2 µm spheres in matching holes
- △ 636 nm spheres in non-matching holes
- × 2 µm spheres in non-matching holes
Modeling the selective removal mechanism

- **Question 1:** Are components lifted out of poorly-matched sites, or do they roll out?

- **Question 2:** Which forces drive the removal (steady or oscillatory, parallel to or perpendicular to the surface?)

- **Answer:** Components are rolled out of poorly-matched sites by a combination of three dominant forces
  - Added mass, Basset, and viscous drag

- **Bottom line:** Yield approaches zero when “removal moment” due to fluid forces exceeds “retention moment” due to adhesion forces, and approaches 100% when retention exceeds removal
Model Verification

Different fluid compositions:
- 4% water: YaA, YbB
- 8% water: YbA
- 20% water: YaB

All data points converge on one curve

Different input voltages
Systematic uncertainty in the experimental parameters leads to uncertainty in the retention to removal moment ratio at which the transition to 100% yield occurs.
Outlook

- TASR offers an effective means of selectively locating components based on their size and shape

- Potential applications in structuring optical or sensor systems, or for shape- and size-selective chromatography

- Agreement between model and experiments over a wide range of experimental conditions suggests that the model may be used as a predictive design tool to guide template structures and assembly conditions to achieve a particular result

- Continuing efforts are focused on extending the approach to other types of systems, demonstrating TASR-based applications, and second generation template manufacturing
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