# Self-assembly of Microsystems

Karl F. Böhringer, Ph.D.
Professor, Electrical & Computer Engineering and Bioengineering
Director, Institute for Nano-Engineered Systems (NanoES)
University of Washington
Seattle, WA, USA

# Part II: Self-assembly by Shape Matching

Wafer-level and massively parallel assembly; assembly by energy minimization; using pallets and templates; how to deal with symmetric parts

# Motivation

<u>Background:</u>

- Since the 1960's, integrated circuits (ICs) have been growing in complexity by about a factor of two every two years ("Moore's Law").
- Since the 1980's, IC technology has increasingly been adapted to build micro sensors and actuators.

<u>Question:</u>

- How does design methodology and manufacturing technology adapt to this increasing complexity and diversity?

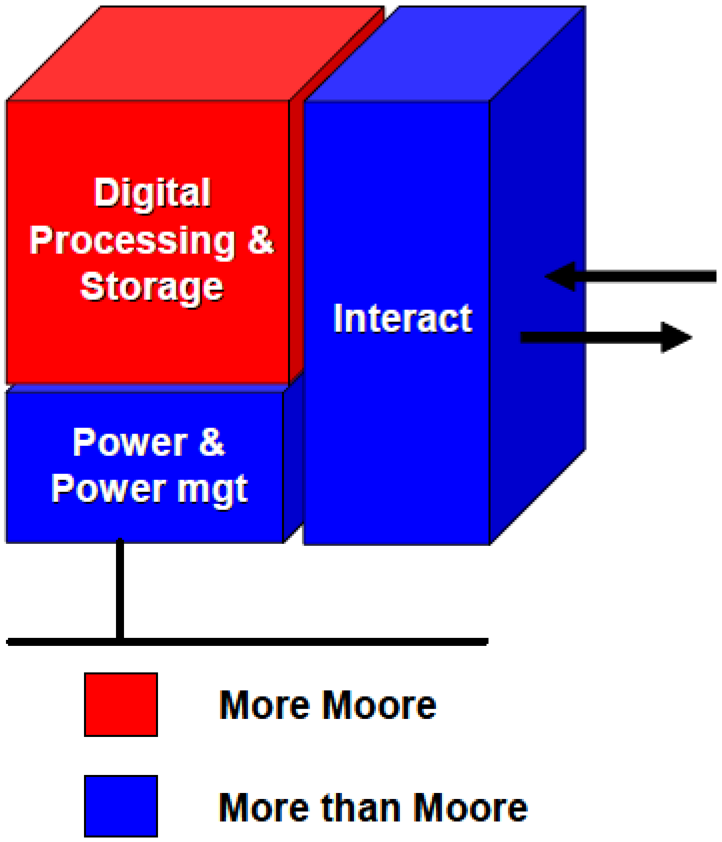
# Motivation

**“More-Moore”: Scaling**

Continued shrinking of physical feature sizes of the digital functionalities (logic and memory storage) in order to improve density (cost per function reduction) and performance (speed, power).

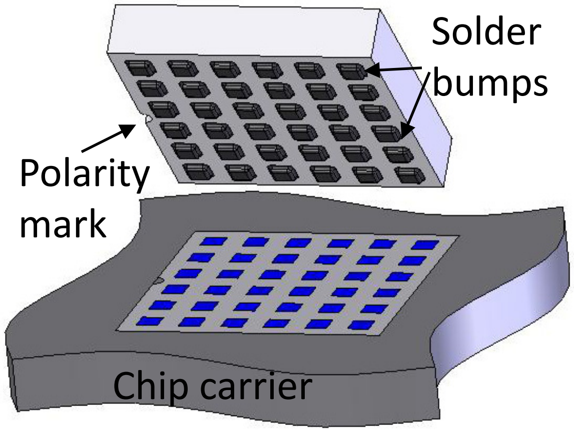
**“More-than-Moore”: Functional Diversification**

Incorporation into devices of functionalities that do not necessarily scale according to "Moore's Law“, but provide additional value in different ways. The "More-than-Moore" approach allows for the non-digital functionalities to migrate from the system board-level into the package (SiP) or onto the chip (SoC).




Wolfgang Arden et al. “More-than-Moore” white paper 2010

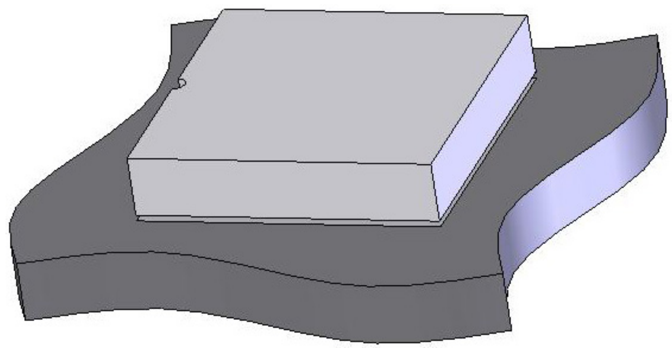
# MEMS Packaging: Flip-chip Bonding




I. Placement

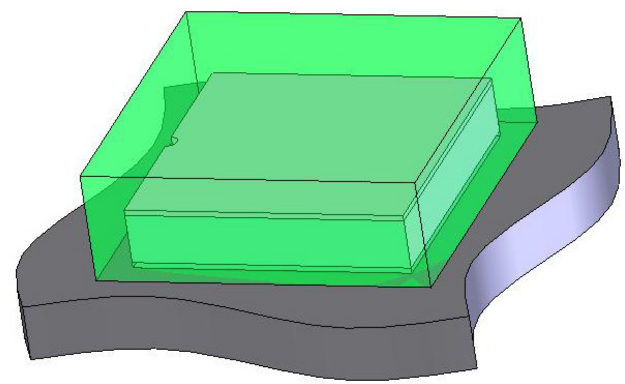
- Unique orientation
- Accurate alignment

- Coplanarity of solder bumps
- Controlled pressure
- Maximum bump density



II. Die attachment
(*solder reflow*)

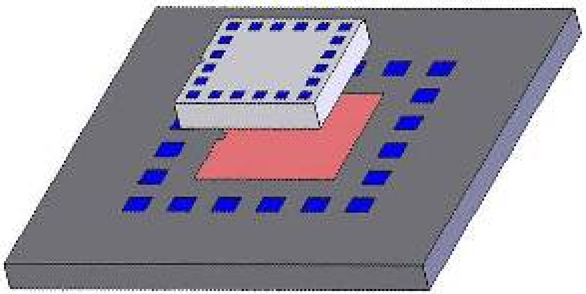
- Protective body
- Heat dissipation
- Vacuum sealing
- Possible optical path



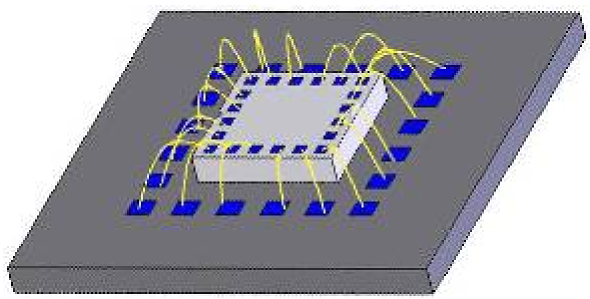
III. Encapsulation

# MEMS Packaging: Wire Bonding

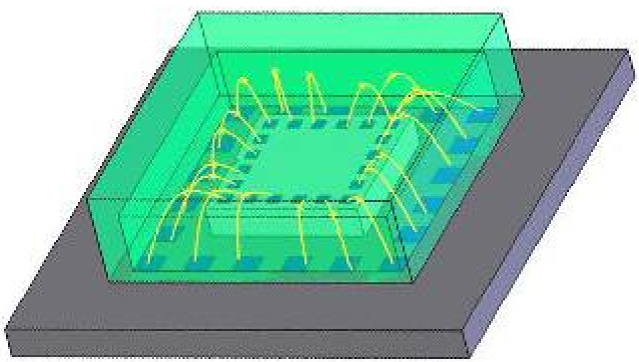
Up to 80% of a MEMS device cost may be determined by its packaging process.



I. Placement



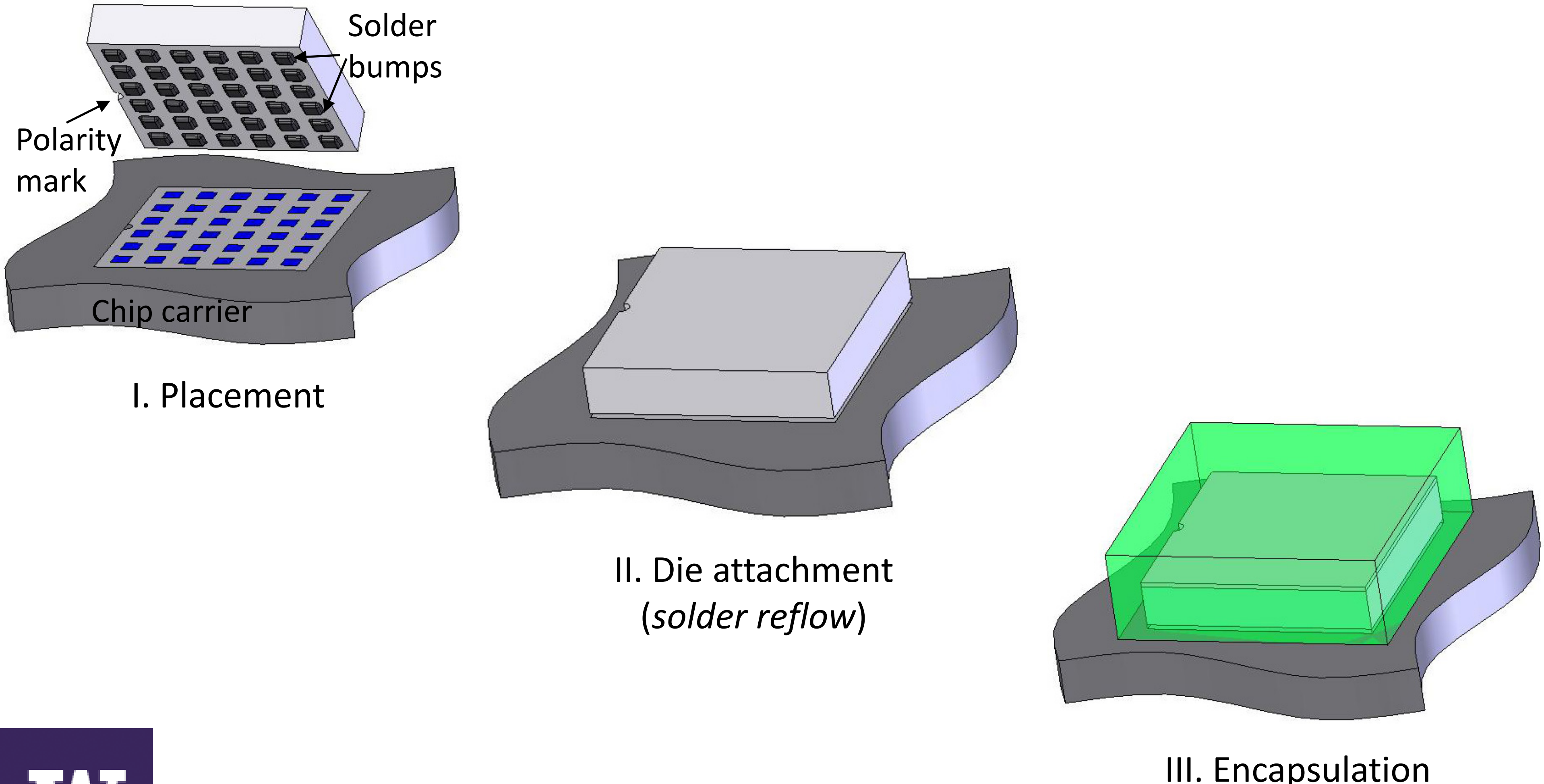
II. Die attachment



III. Encapsulation

Greater misalignment tolerance than flip-chip bonding.

# Chip Placement by Self-assembly



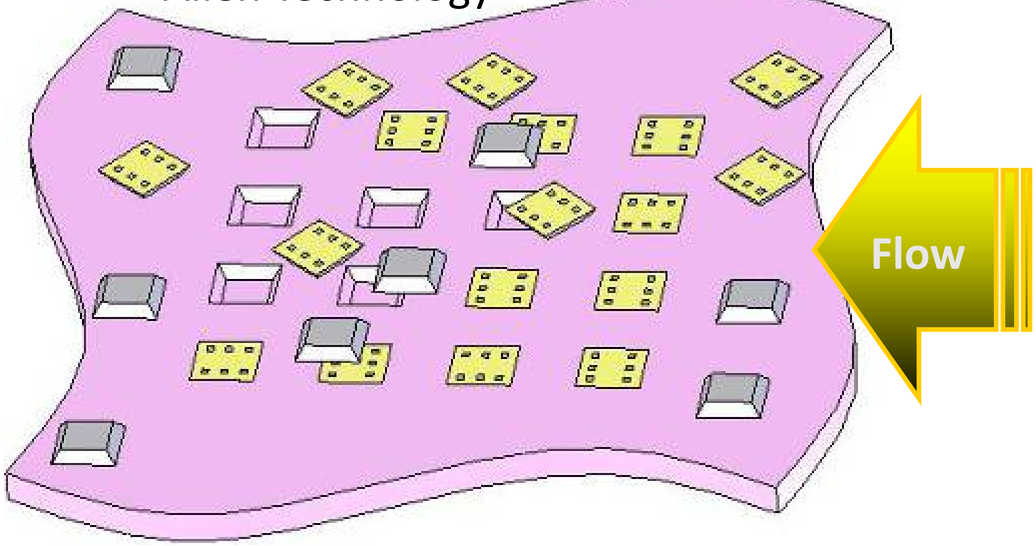
# “Palletizing” of Assembly Components

- Self-assembly (or conventional assembly) may deliver the components into their final position.
  - Example: RFID chips in Alien Technology’s FSA.

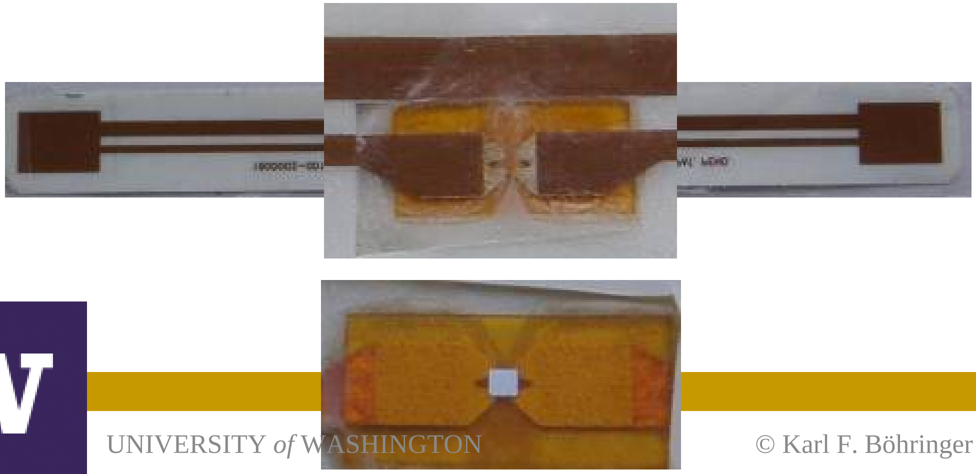
- Alternatively, they may provide an ordered arrangement from which the final assembly can be achieved efficiently.
  - Example: wafer-level transfer and bonding.

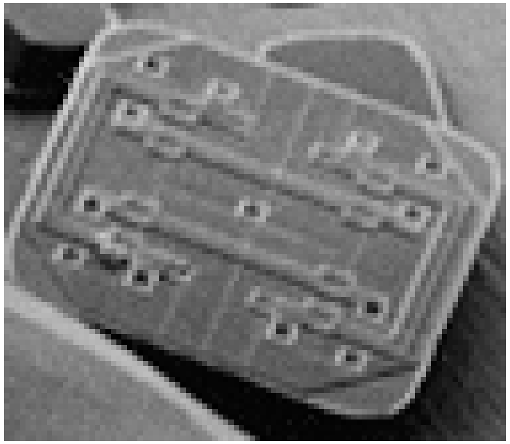
# Fluidic Self-assembly with Shape-matching

Alien Technology

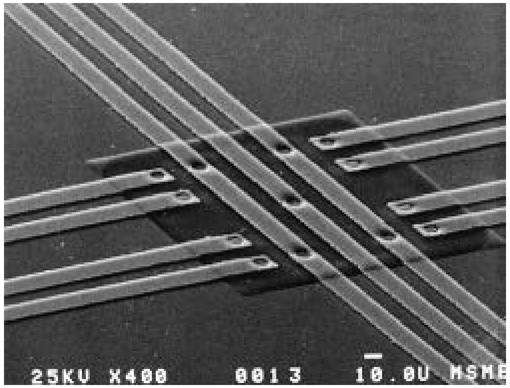



Application: RFID tag fabrication



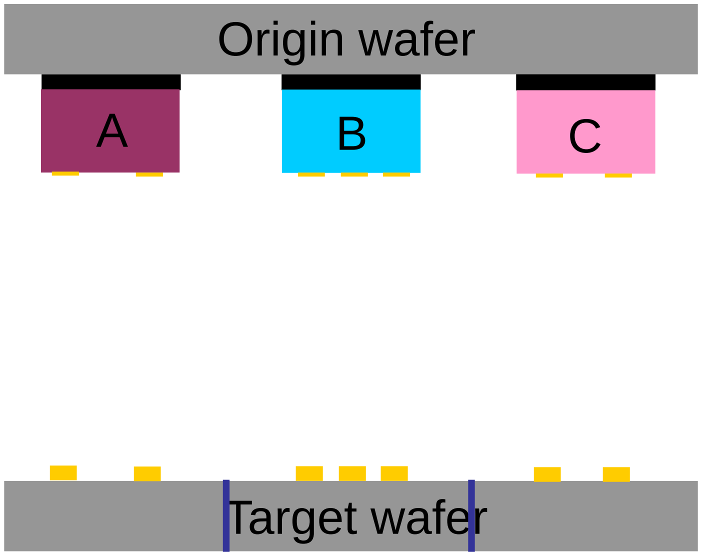


Nano block




Electrical wiring

# Wafer-to-wafer Transfer



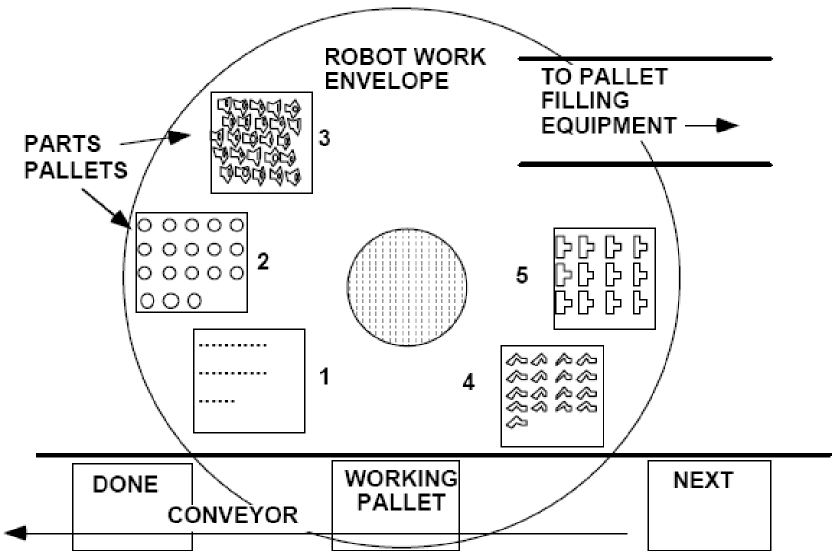

- Au bump
- Sacrificial layer

Dicing

# Compare: Robotic Parts Feeding

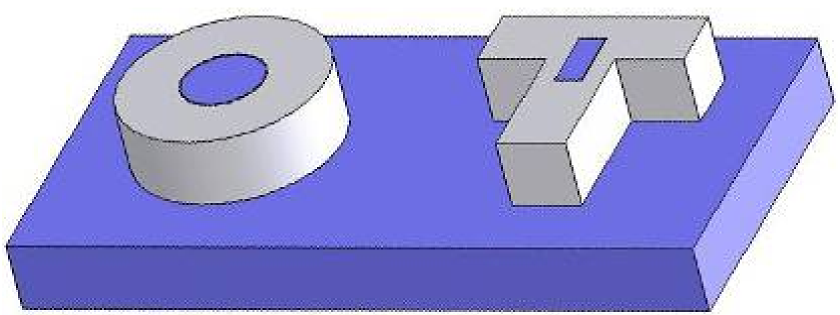
- Palletizing is very common in robotic assembly.
- Parts are delivered in bulk, typically into a vibratory parts feeder.
- The vibratory parts feeder is designed such that parts separate and move along tracks with obstacles that let correctly oriented parts through but reject wrongly oriented parts.
  - Each part requires a new track design.
- SONY's APOS became famous for using shape-matching in parts feeding.
  - The design of their trays was considered a "black art".

# Robotic Parts Feeding and Assembly

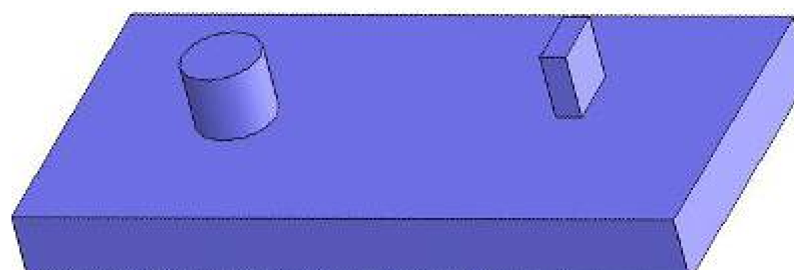



**Part feeding**

**Pick and place**



**Assembled parts**



**Fixtures on substrate**

# Shape Matching Self-assembly

Self-assembly by shape matching can occur in a liquid environment (e.g., fluidic self-assembly by Alien) or in air

1. Structured particles: the components have complementary shapes that fit into each other in a unique way
2. Binding force: gravity or surface forces (capillarity, van der Waals, electrostatics)
3. Environment: a fluid helps with the delivery of components
4. Driving force: agitation provides transport while the system minimizes potential energy during assembly

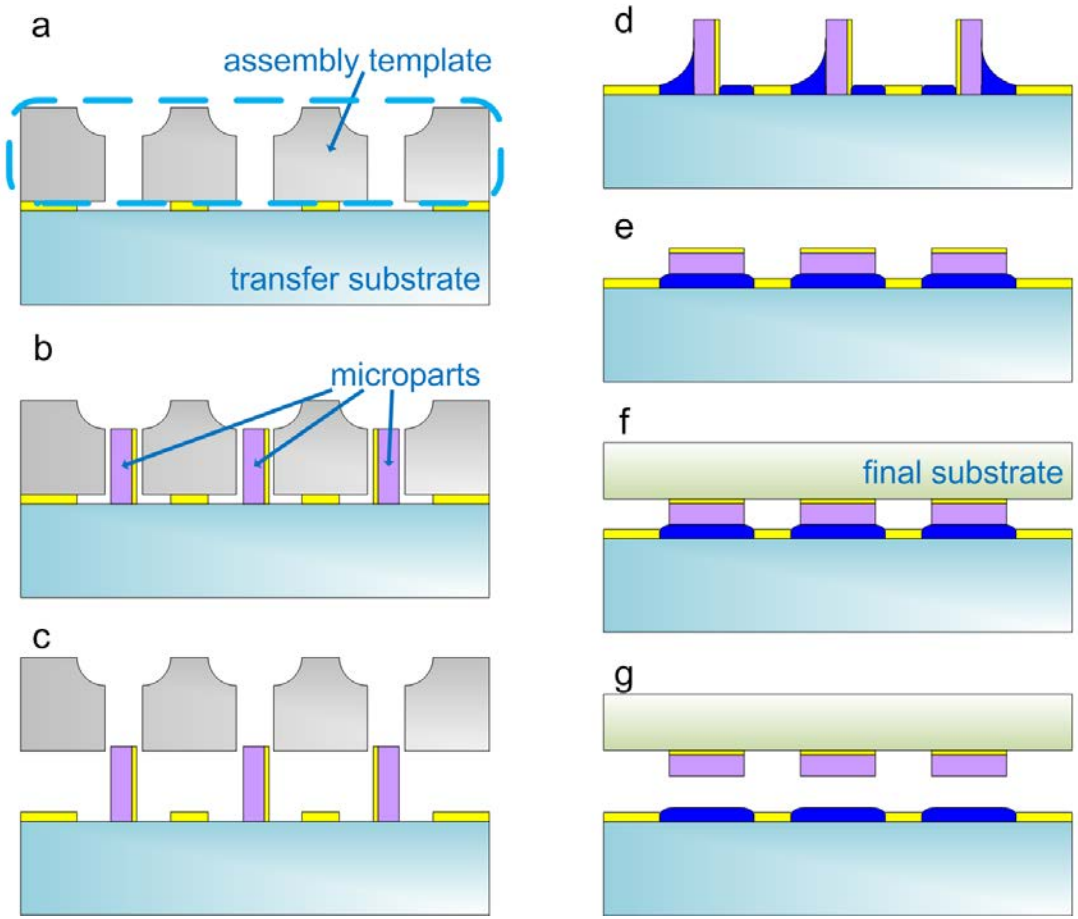
# Example 1: Palletizing Parts in a Shape-matching Template

Applications: flip-chip, SMT assembly

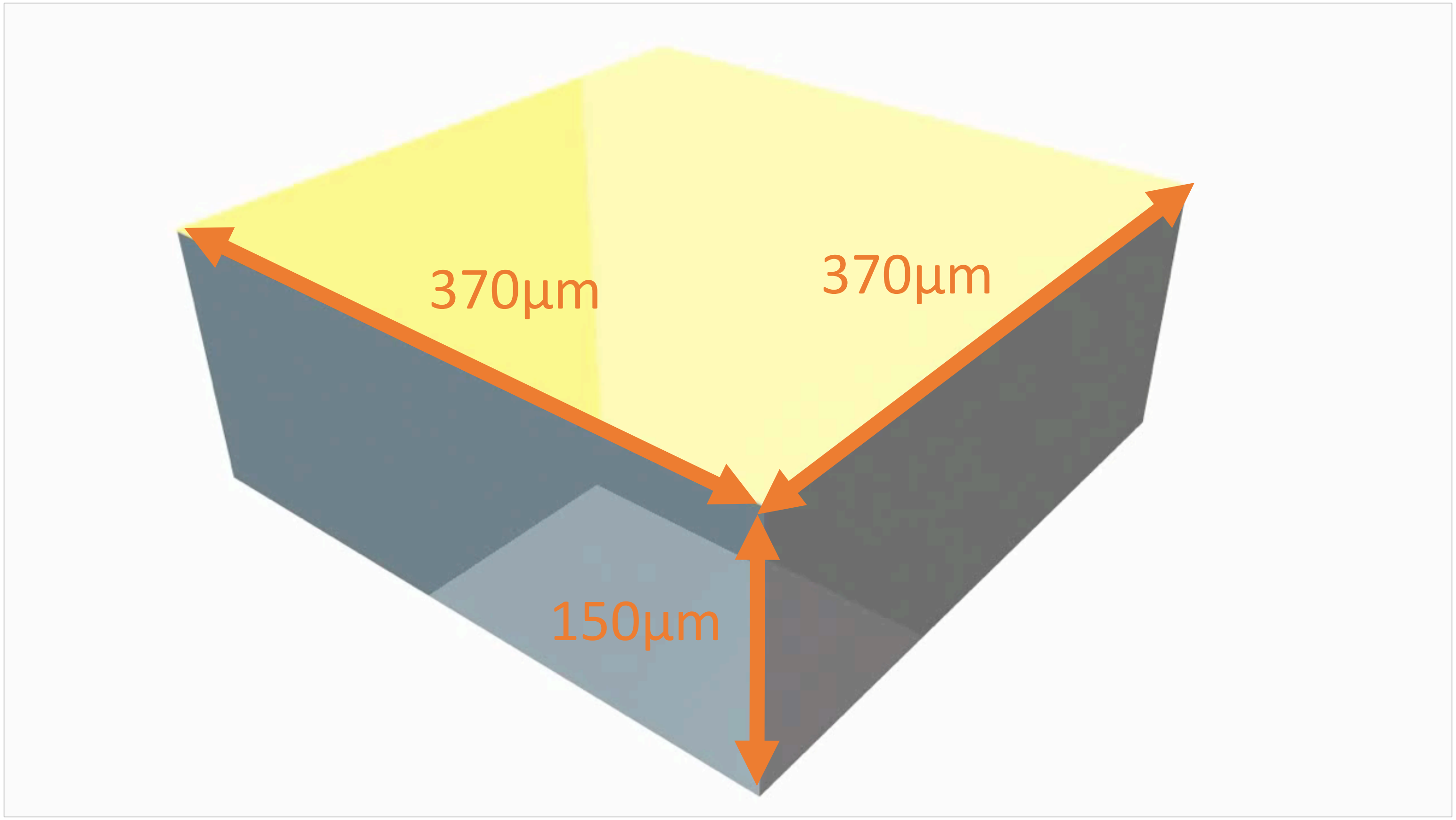
# Templated Self-assembly

- Parts are delivered in a random walk driven by vibration
- Parts fall into vertical slots
  - This provides highest density in assembly template
- Template is removed, parts remain on assembly substrate
  - Capillary forces help with accurate alignment and attachment

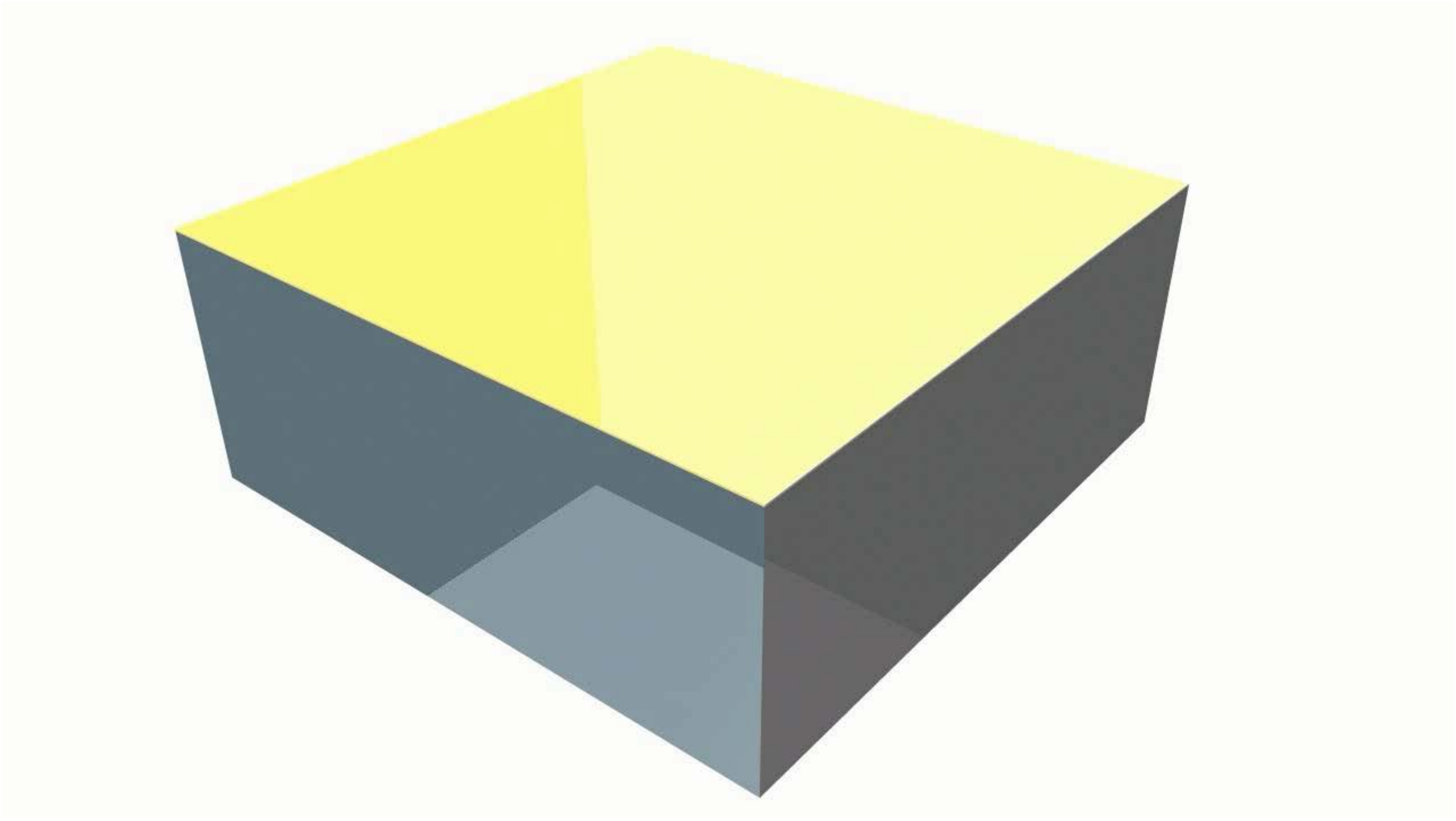
# Assembly Process Flow



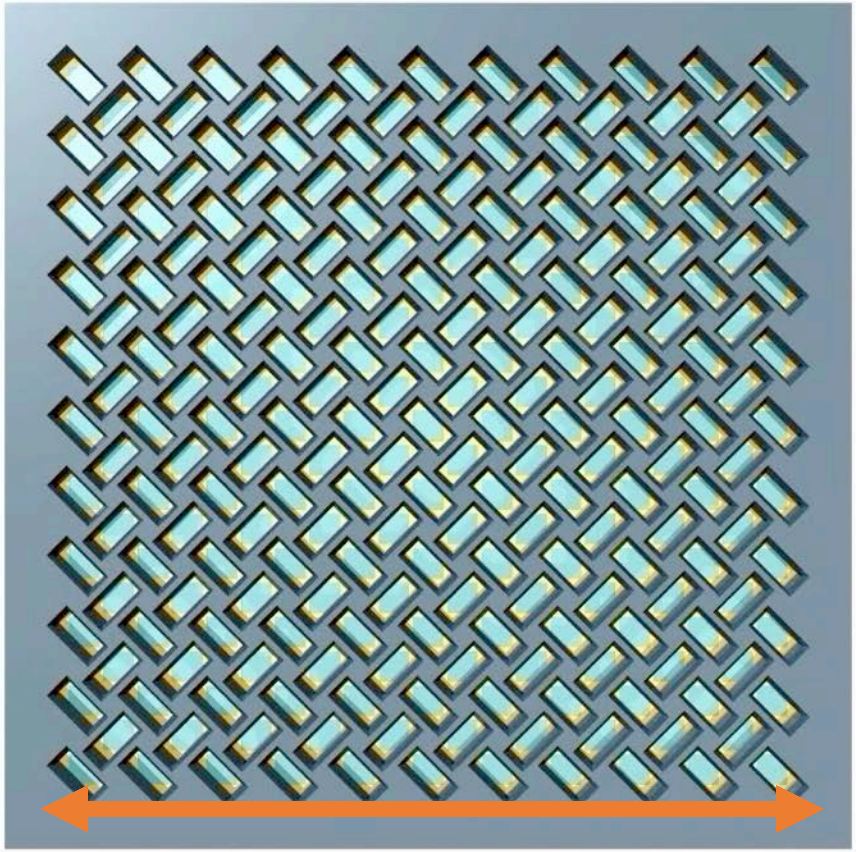
# Components: Microparts



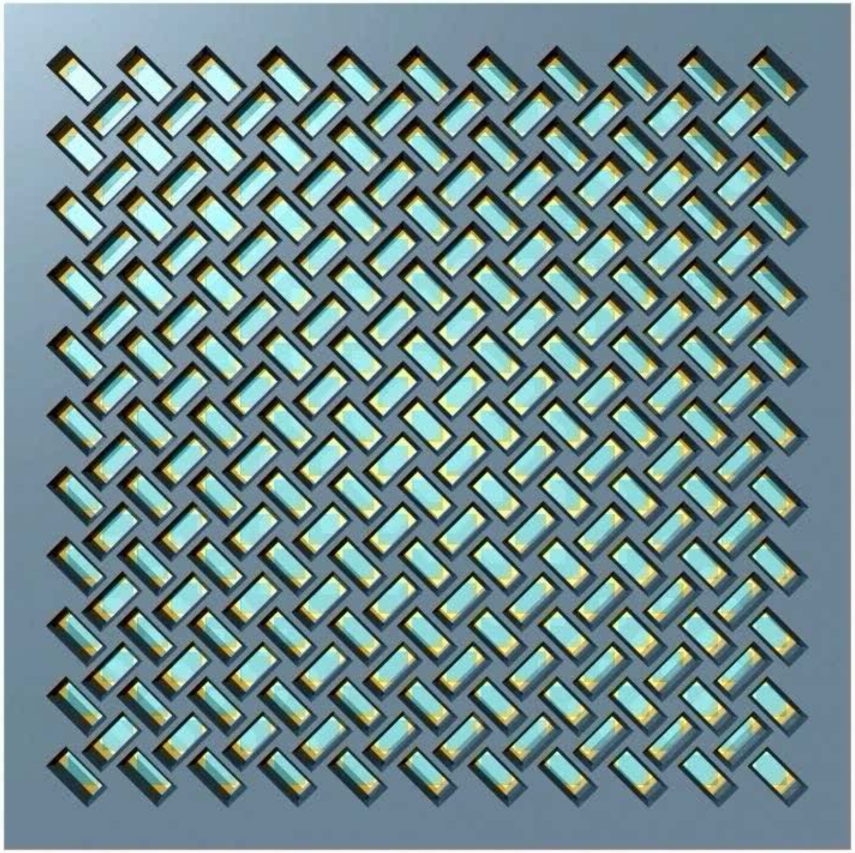
# Components: Microparts



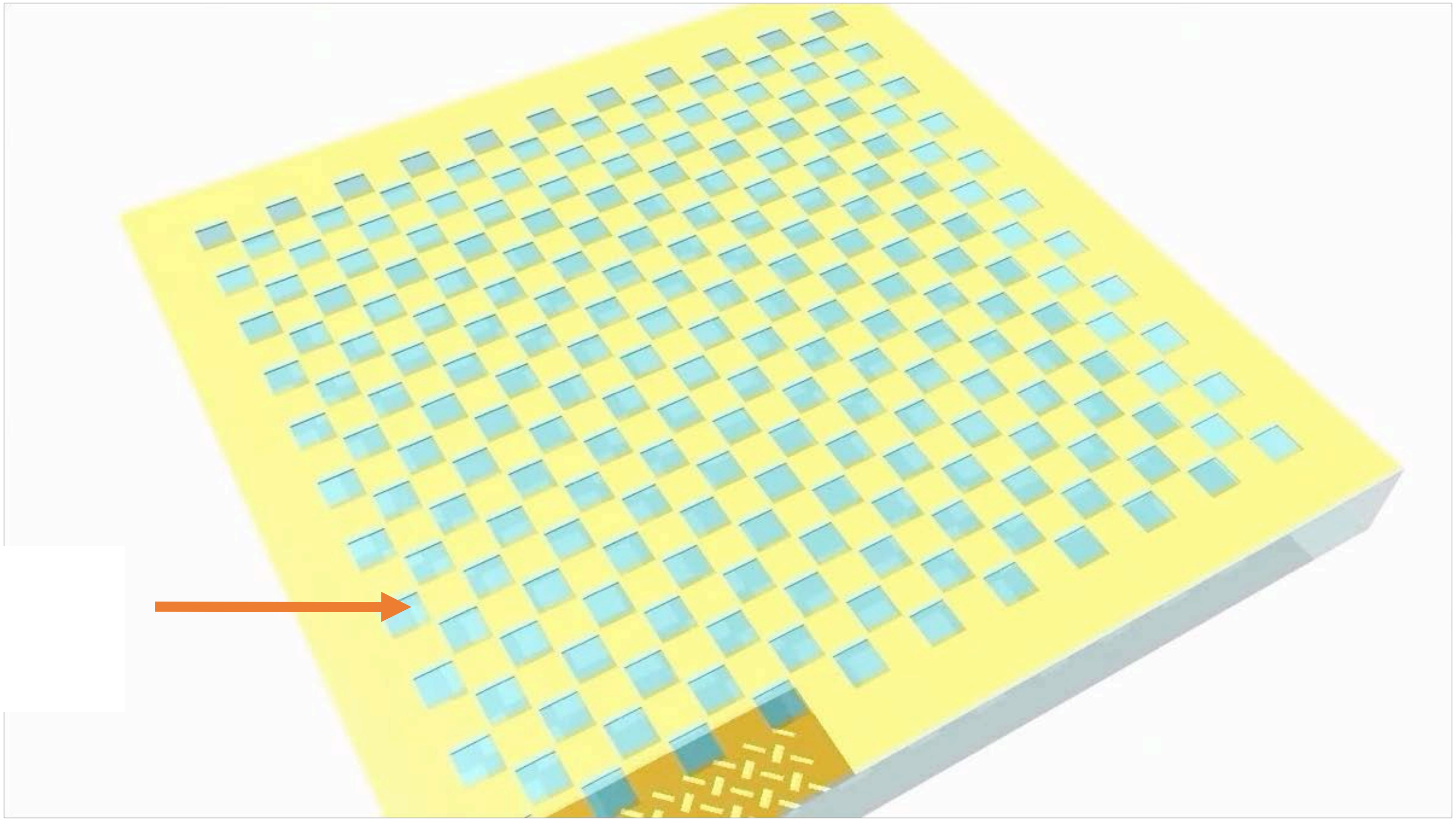
# Assembly Template



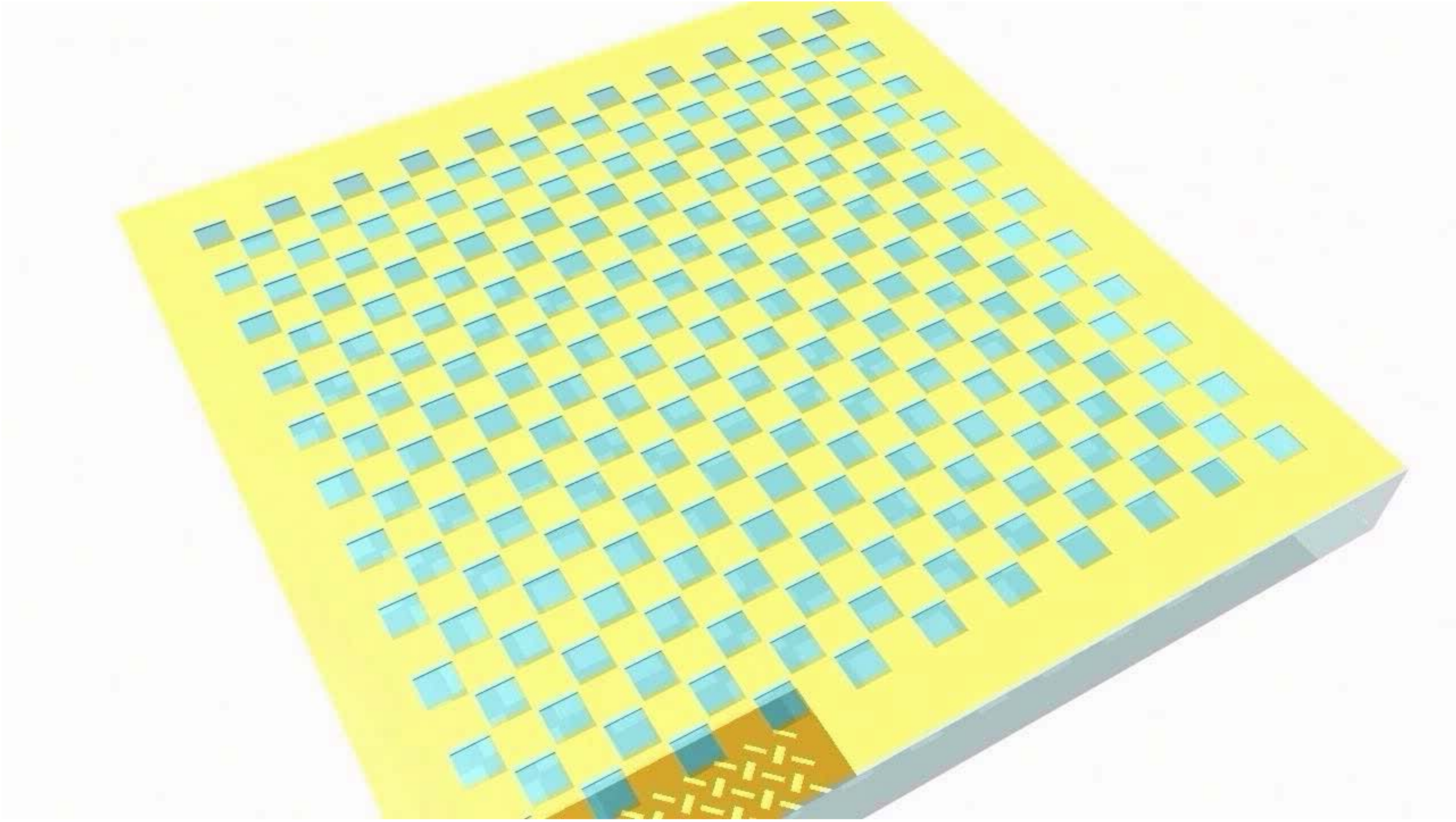
# Assembly Template



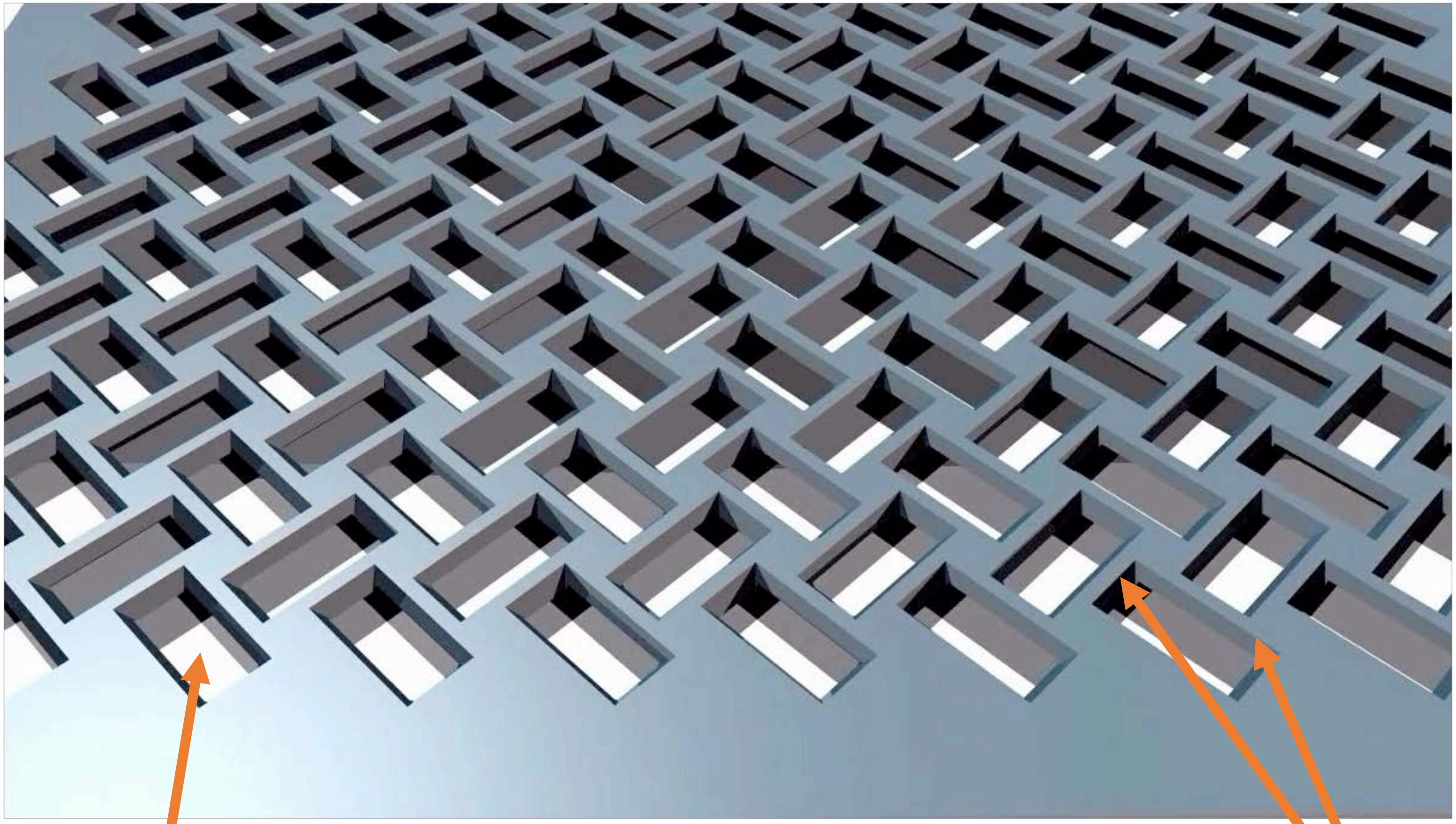
# Transfer Substrate



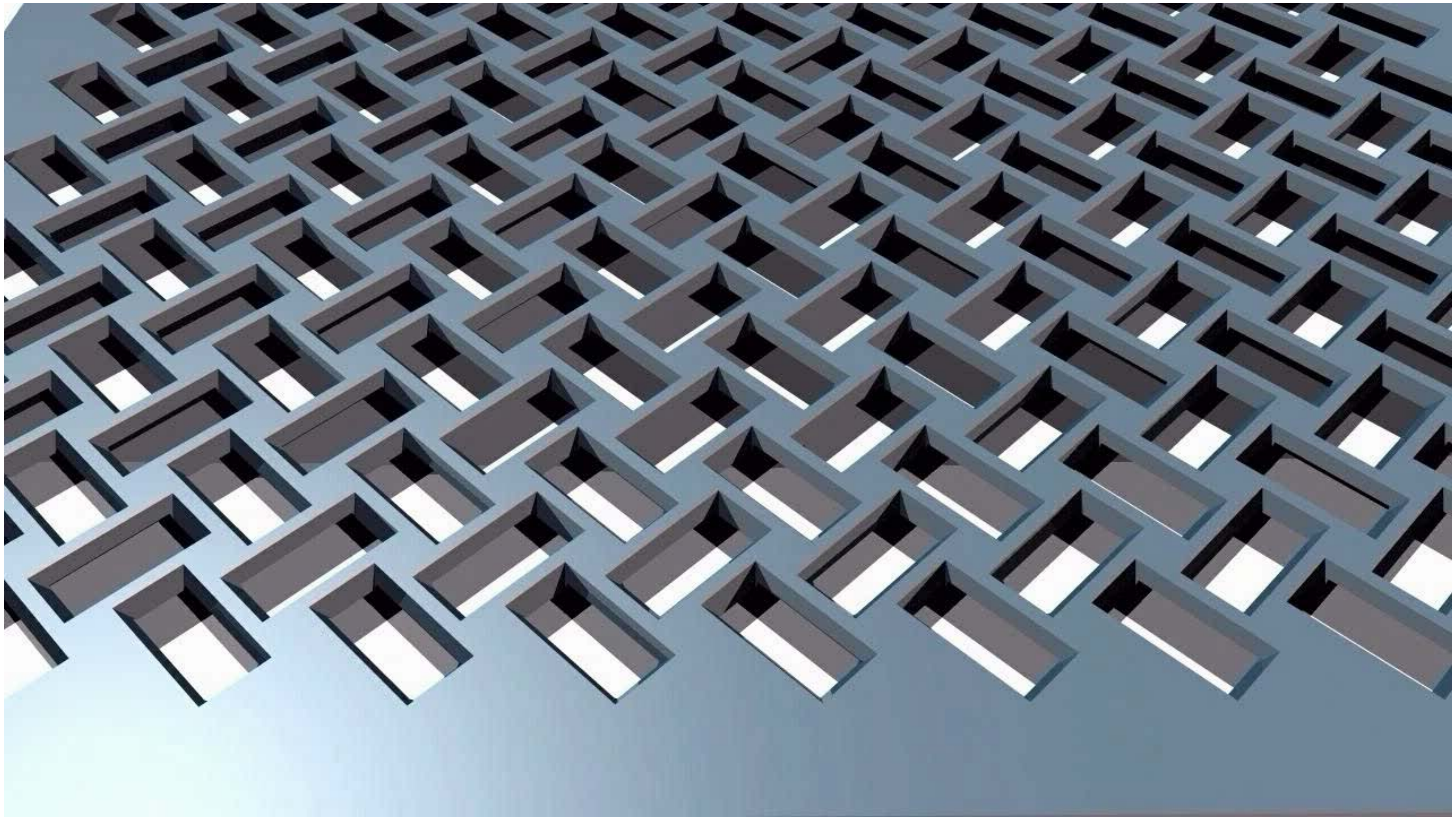
# Transfer Substrate



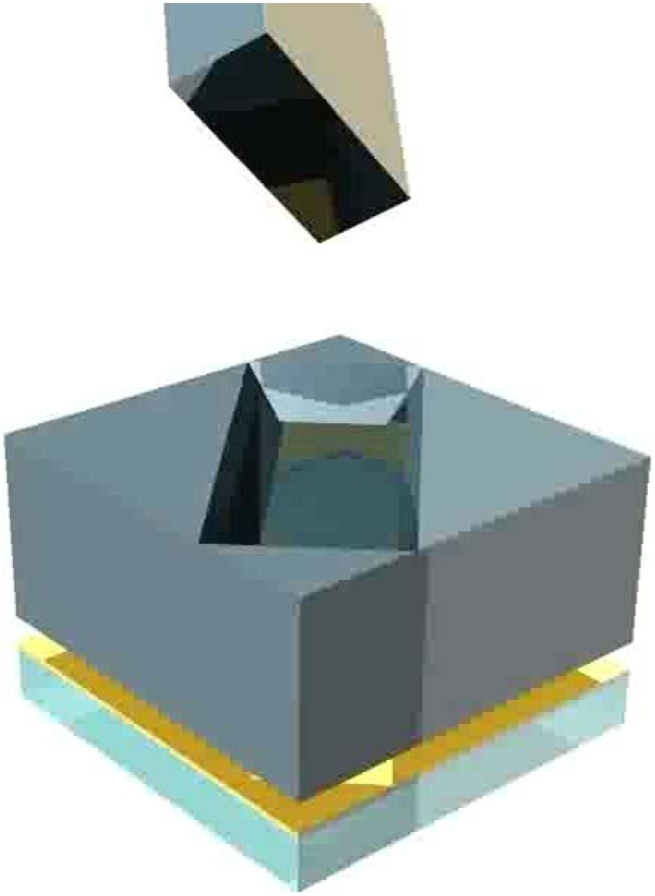
# Assembly Template



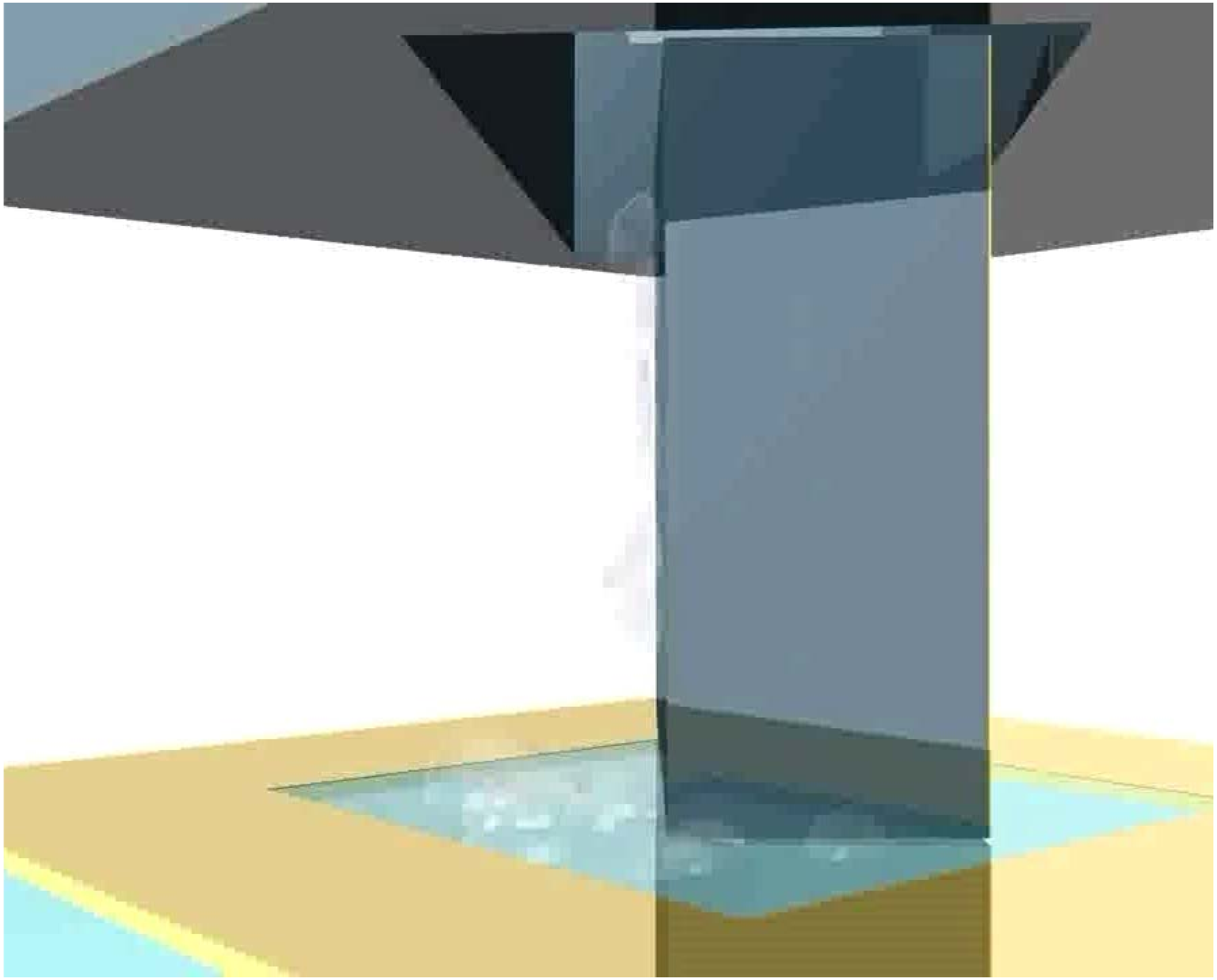
# Assembly Template



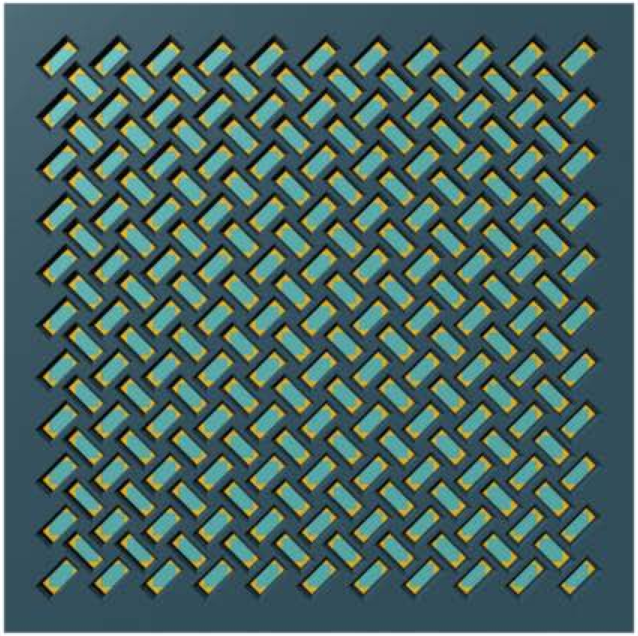
# Templated Self-assembly Process



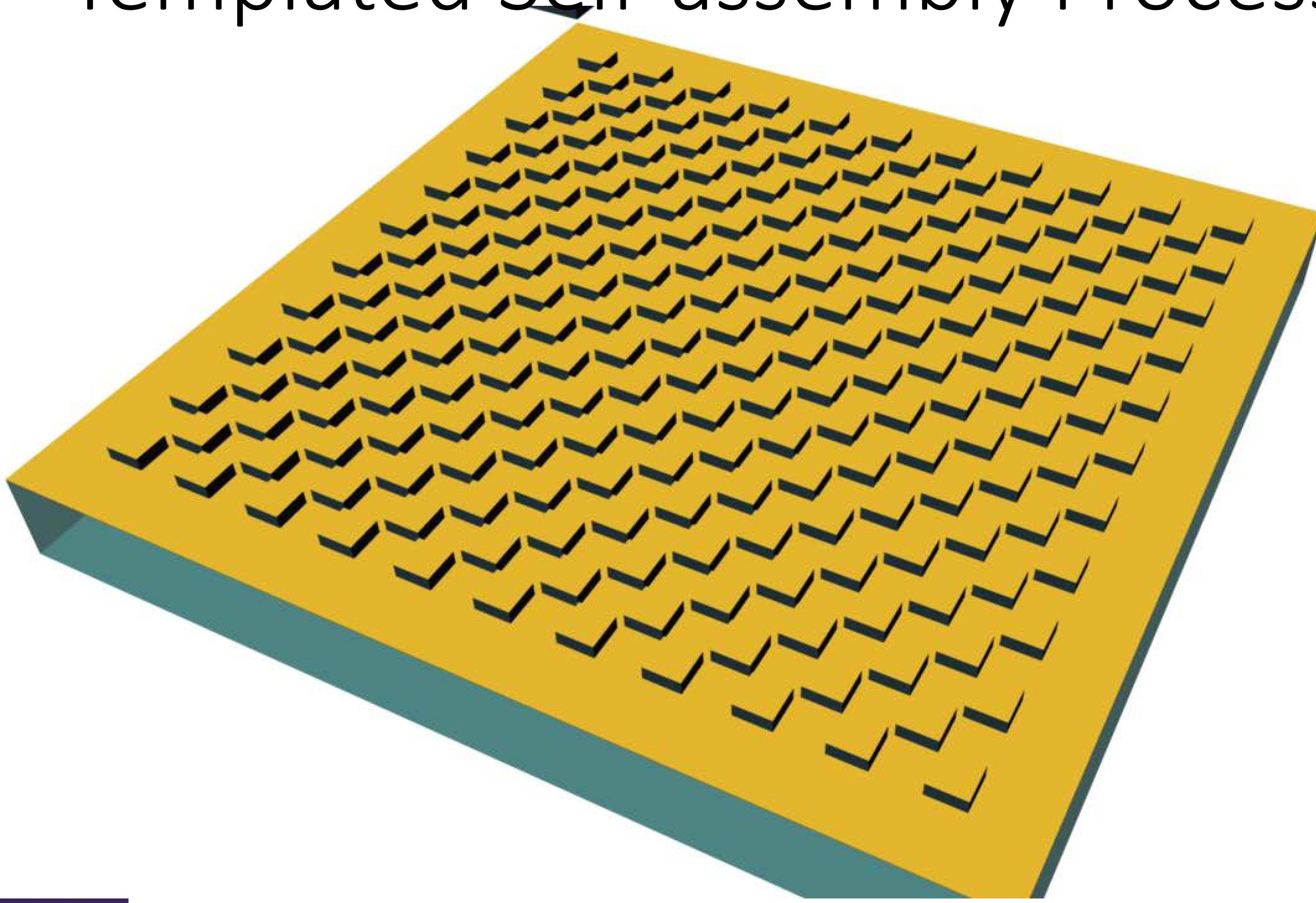
# Templated Self-assembly Process



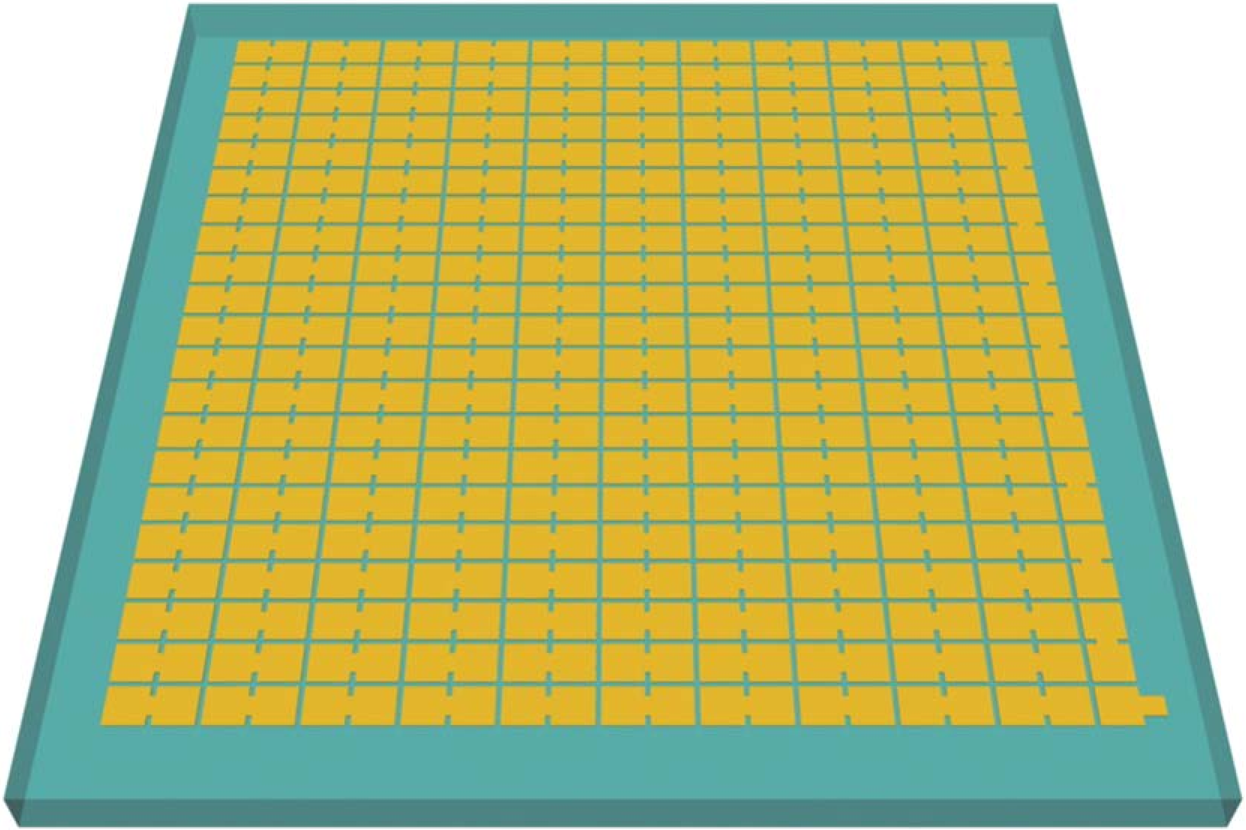
# Templated Self-assembly Process



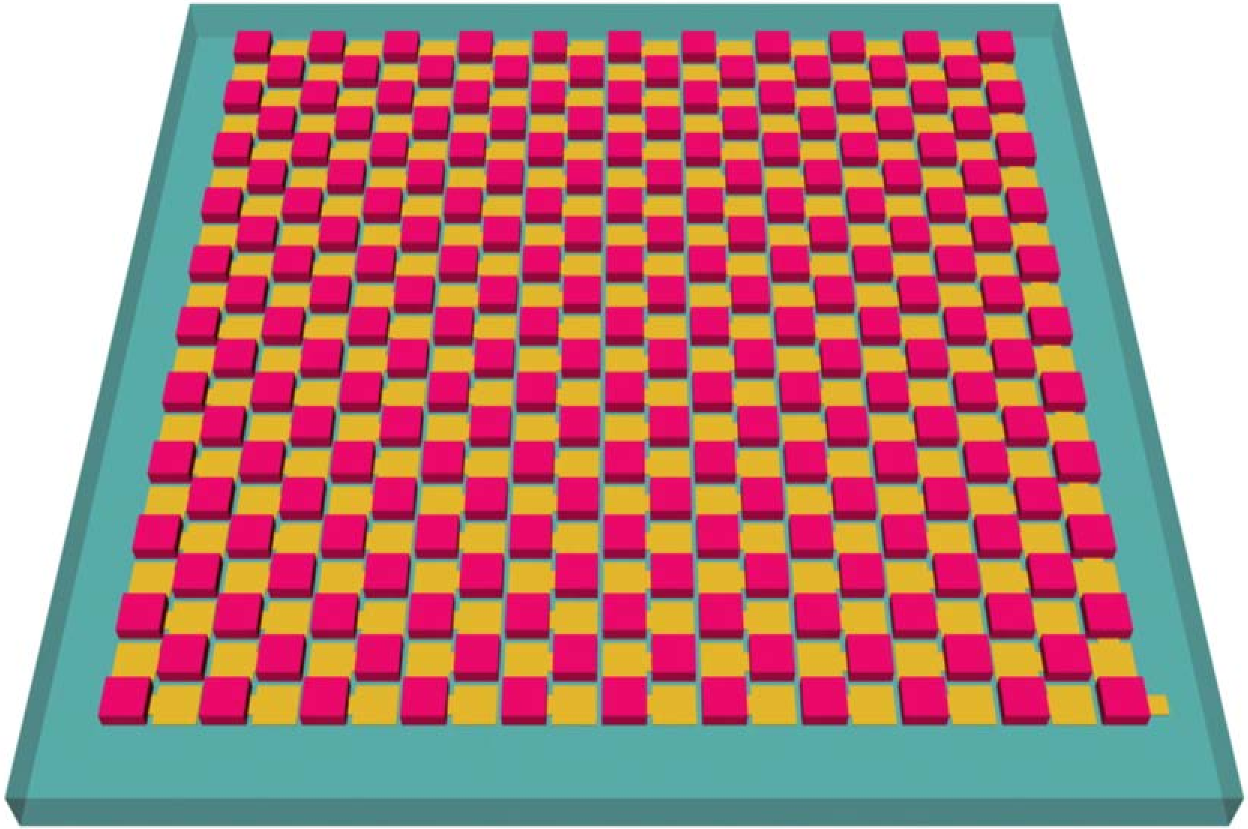
# Templated Self-assembly Process



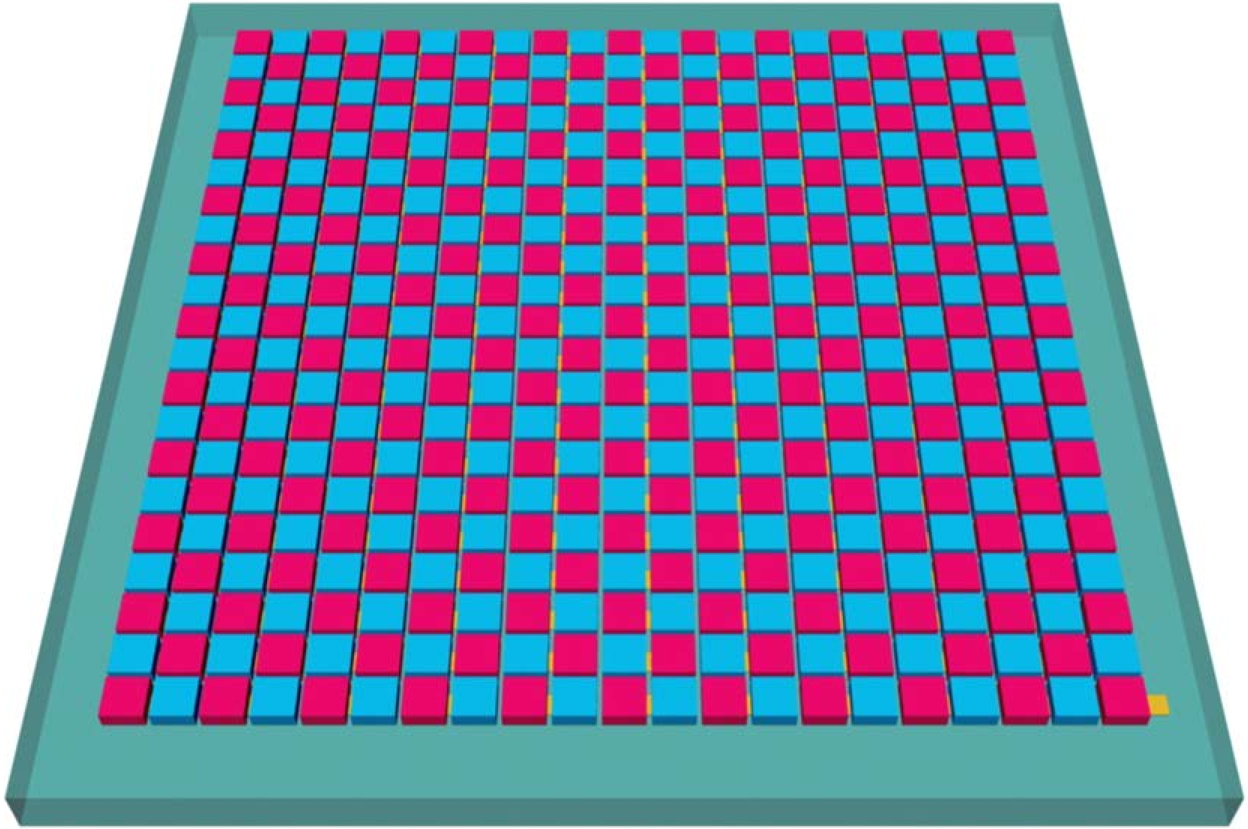
# Templated Self-assembly Process



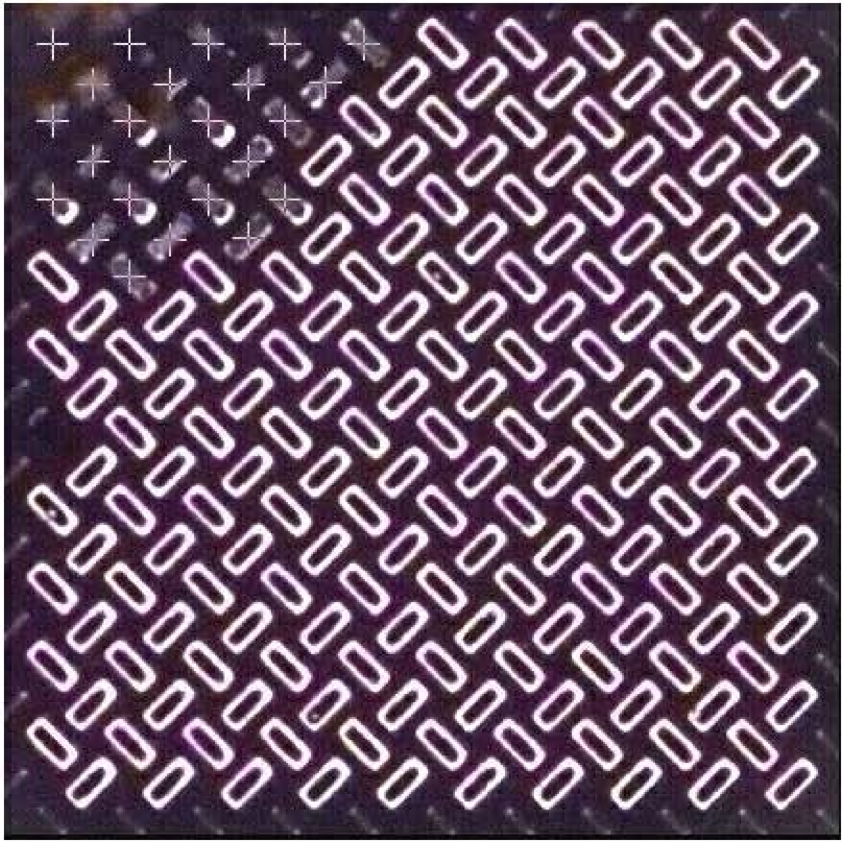
# Templated Self-assembly Process

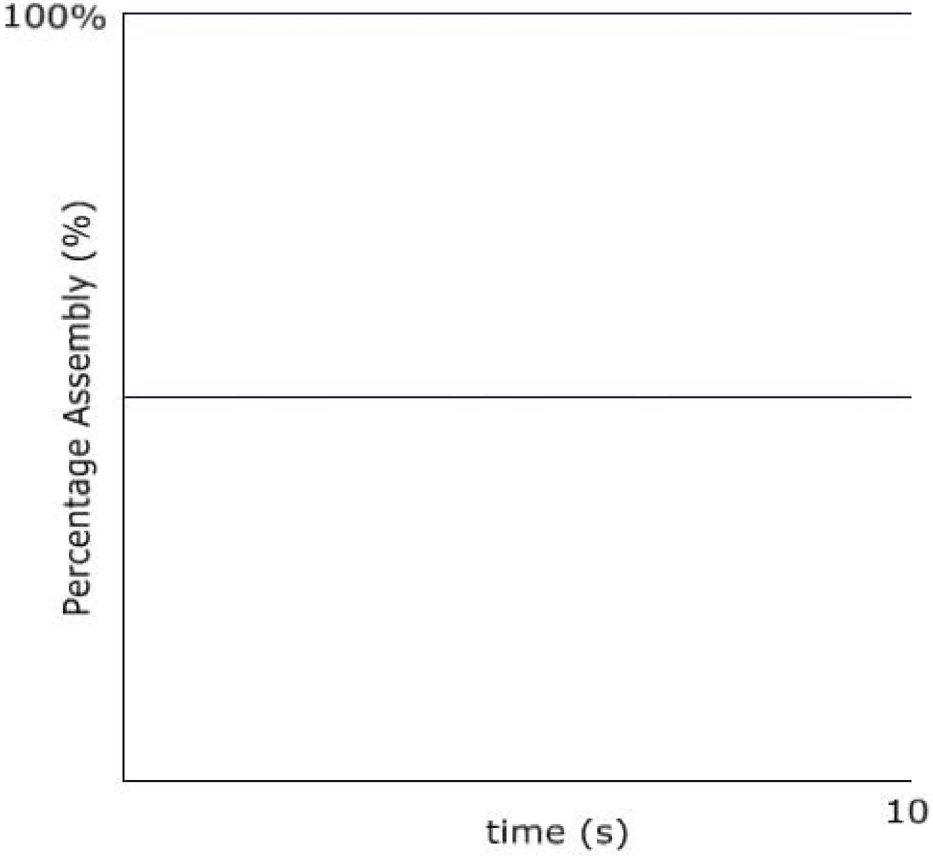


# Templated Self-assembly Process



# Vibratory Delivery for Self-assembly

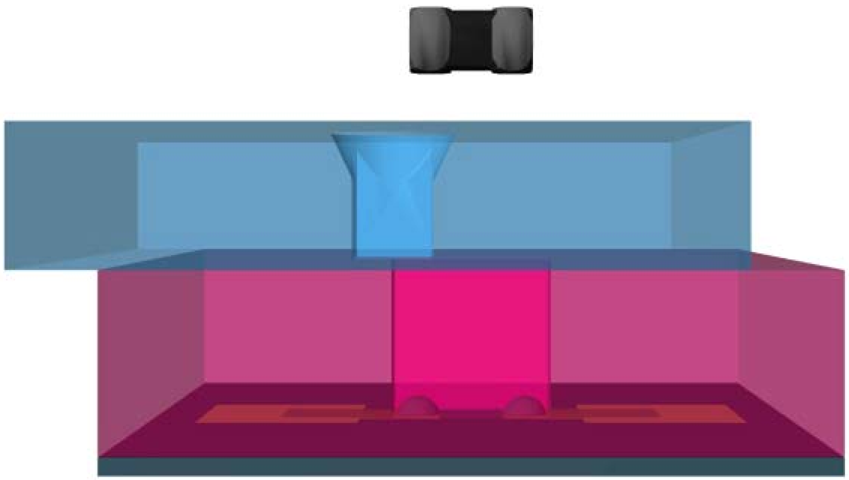




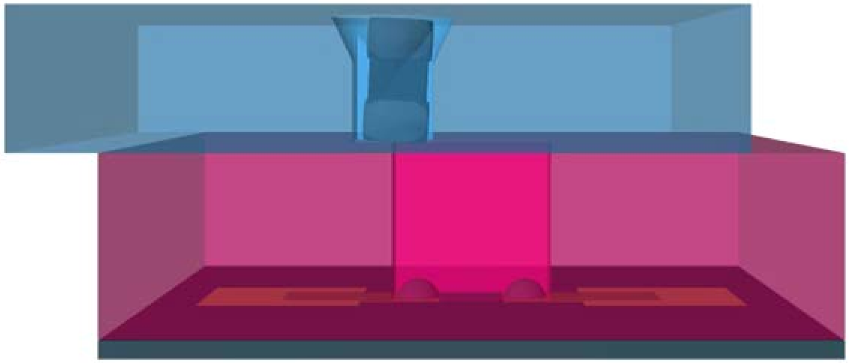
# Self-assembly of Surface Mount Technology Components

- Shape-matching assembly with vertical template
- Enforce exactly one component per site
- Symmetry of simple SMT components does not pose difficulties (except for diodes)

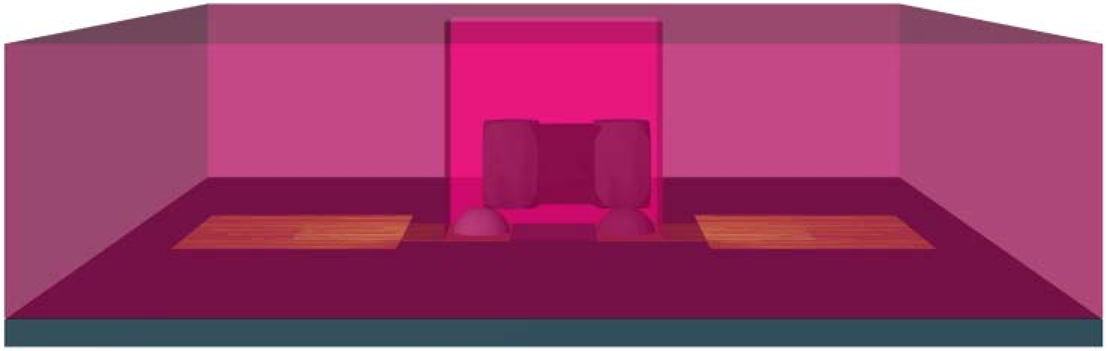
# 01005 SMT Self-assembly



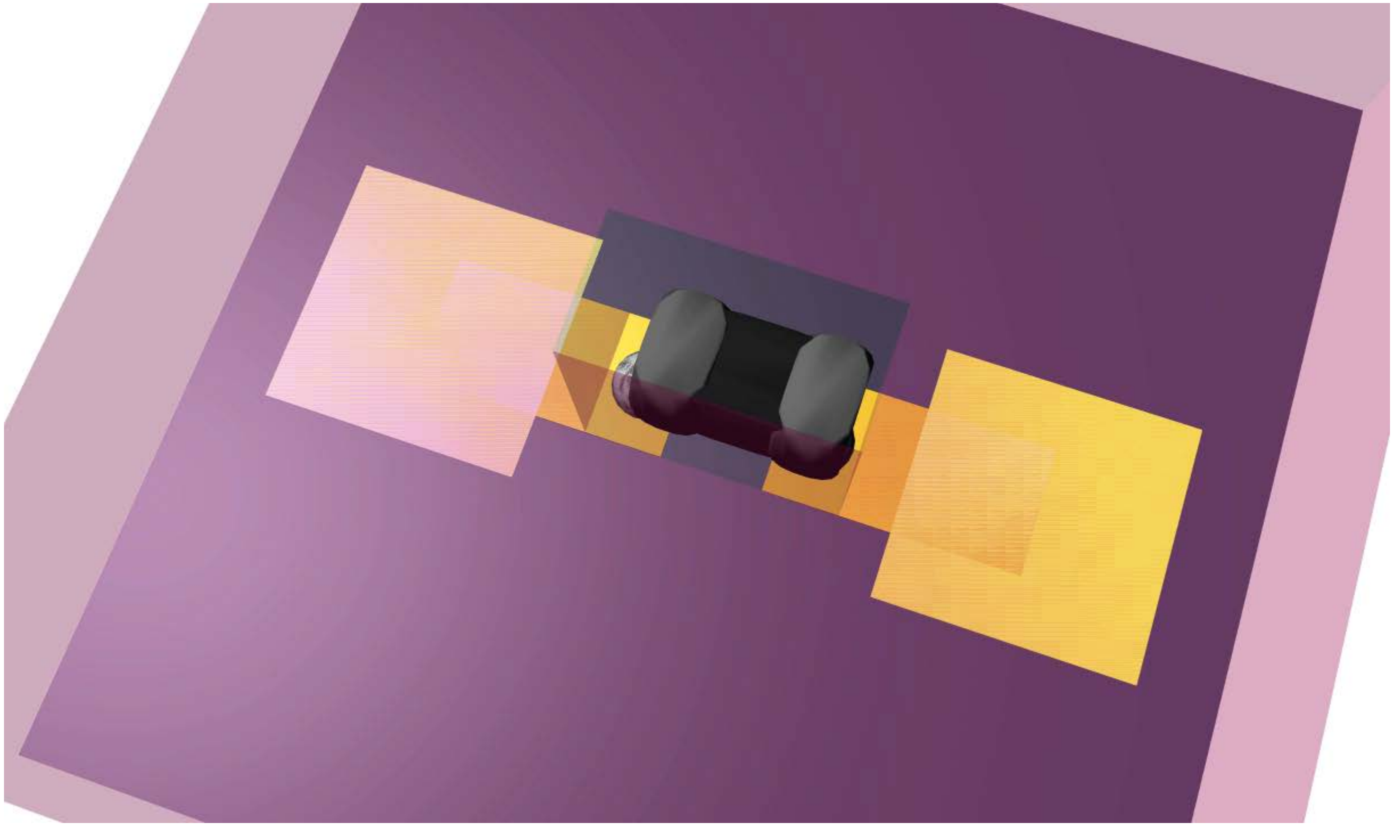
# 01005 SMT Self-assembly



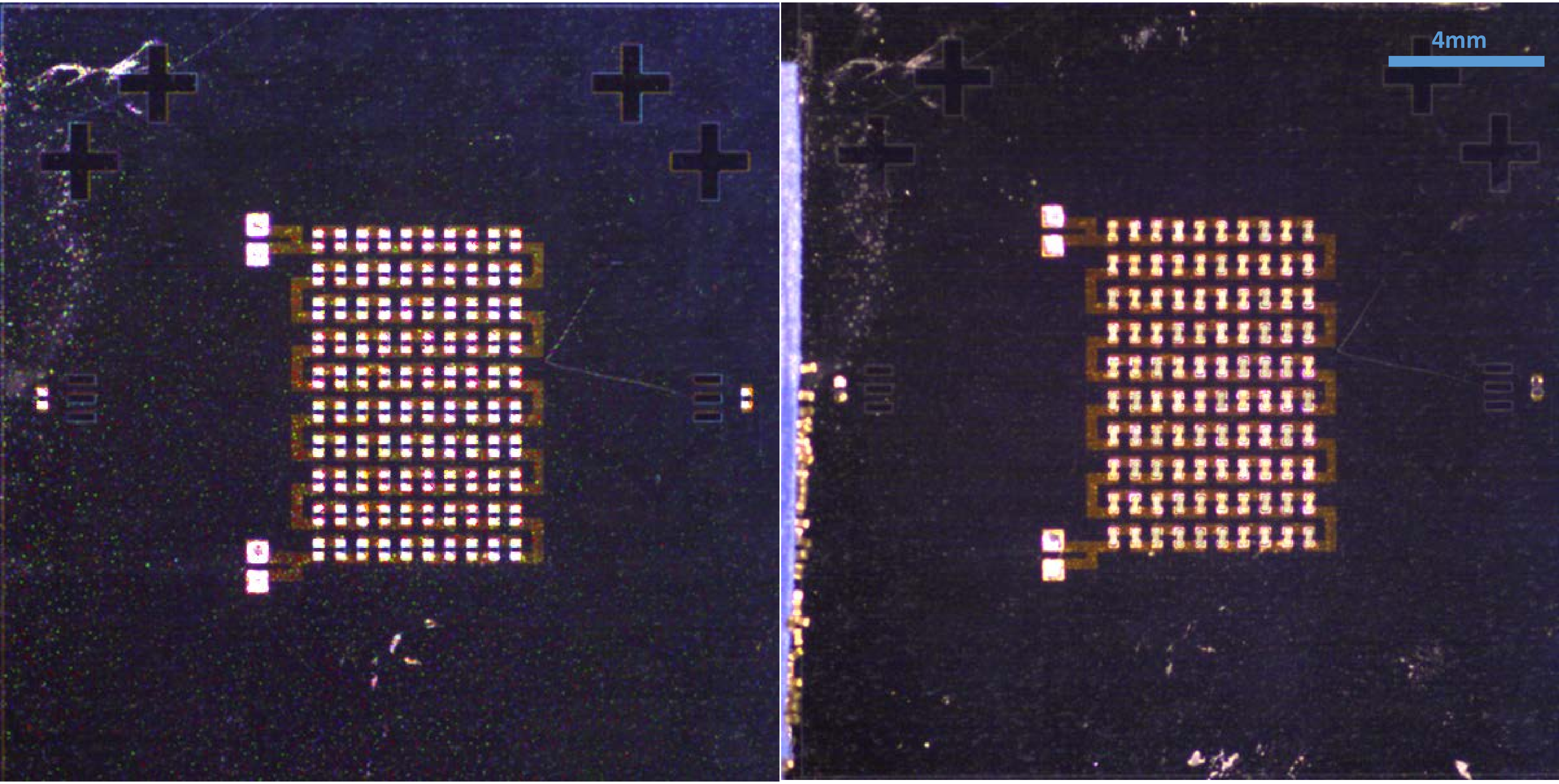
# 01005 SMT Self-assembly



# 01005 SMT Self-assembly

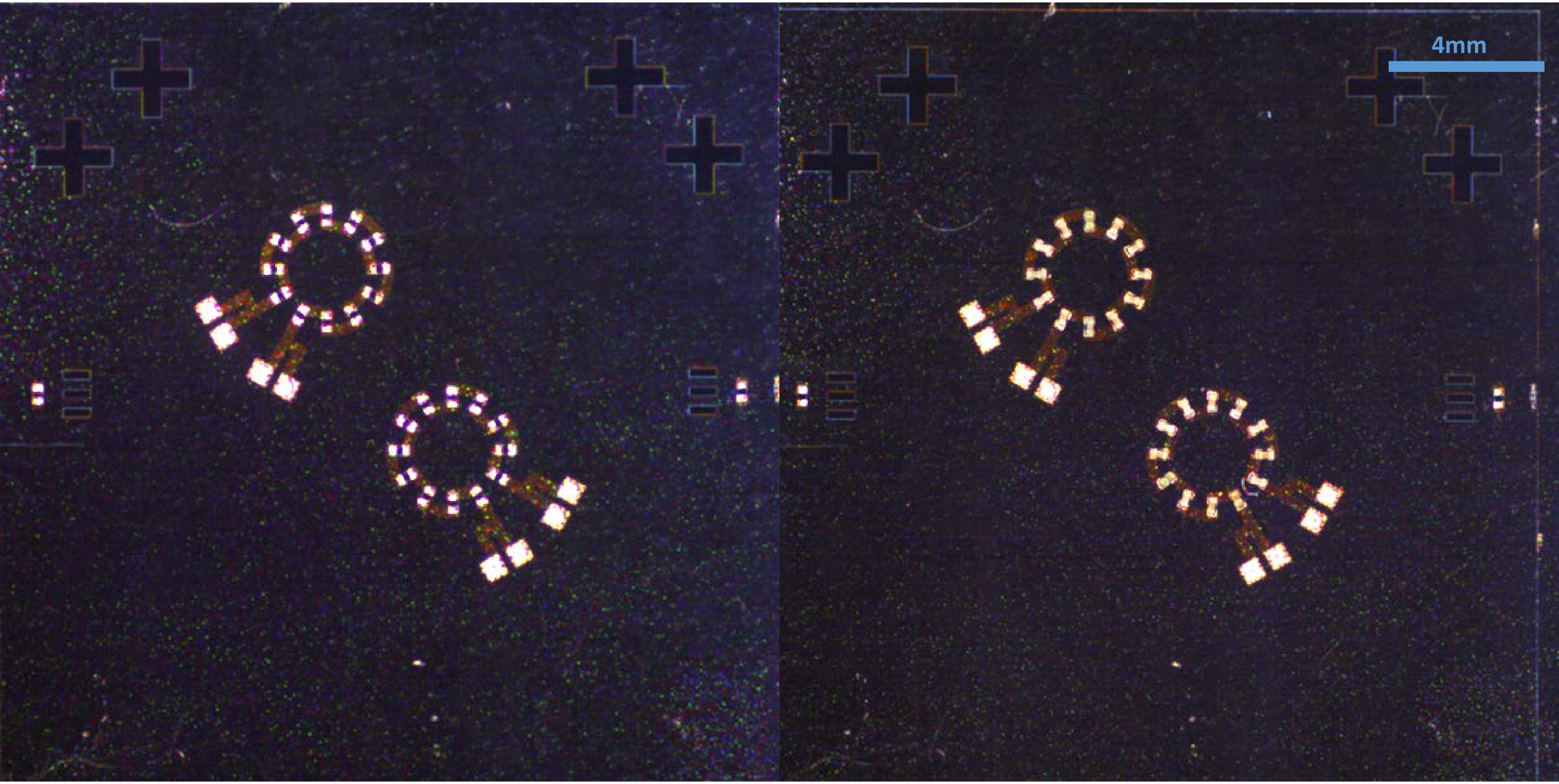


# SMT Self-assembly Results




100 component series circuit assembly

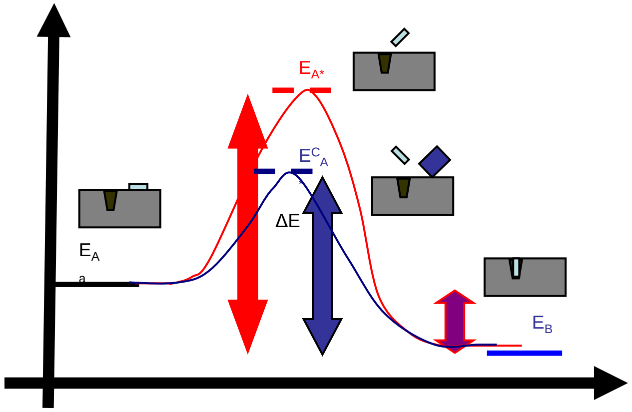
# SMT Self-assembly Results

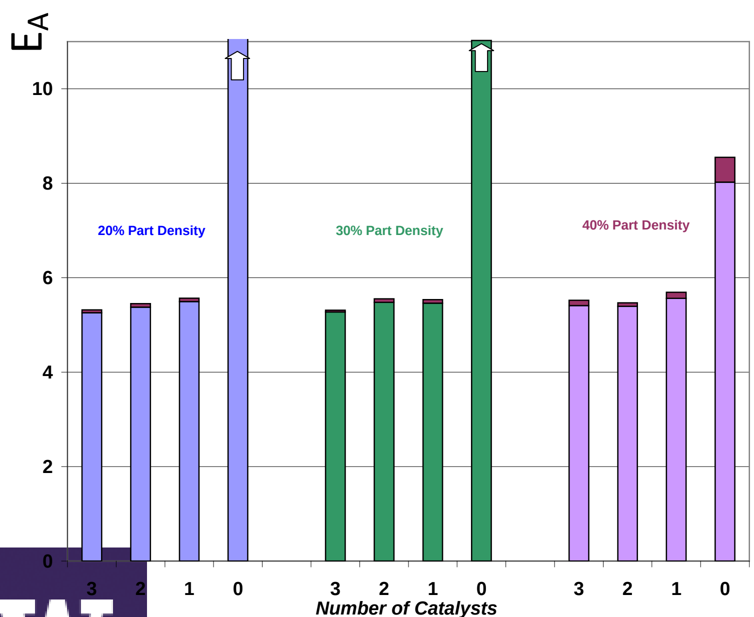


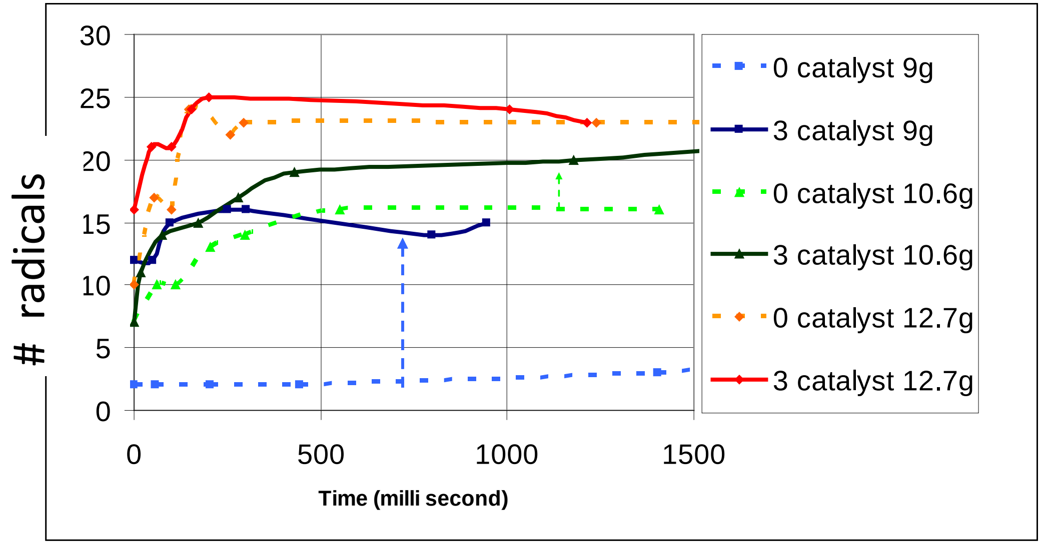

Circular 12 component series circuit assembly

# Micro-self-assembly Catalysts

Introduce components that increase number of 'free radicals' but do not interfere with assembly sites
[*IEEE MEMS '08*]



# Example II: Shape-matching with Unique Orientation

Challenge in self-assembly: symmetric component geometries

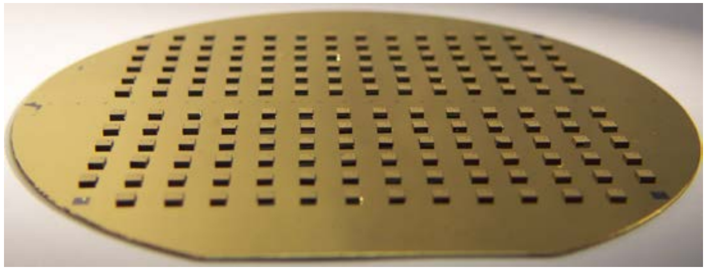
# Self-assembly with Symmetric Components

- If the components are symmetric with regards to the assembly forces then the component cannot be assembled into a unique orientation.

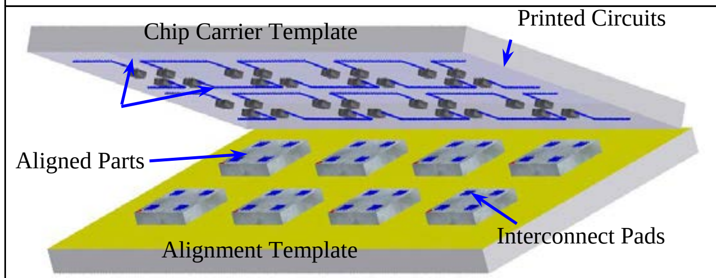
- Solutions:
  1. Components have to be designed with symmetry (e.g., redundant bond pads).
  2. Features have to be added that break the symmetry.

# Batch Packaging of Micro Devices with Uniquely Orienting Self-Assembly in Air

- To assemble microchips with multiple interconnect pads, the alignment orientation must be unique to achieve correct electrical connections to the chip carrier template.
- The major two steps: (1) face orienting and palletizing parts onto an alignment template; (2) trapping and uniquely aligning parts to binding sites.
- [J. Fang et al. *IEEE MEMS* '05]



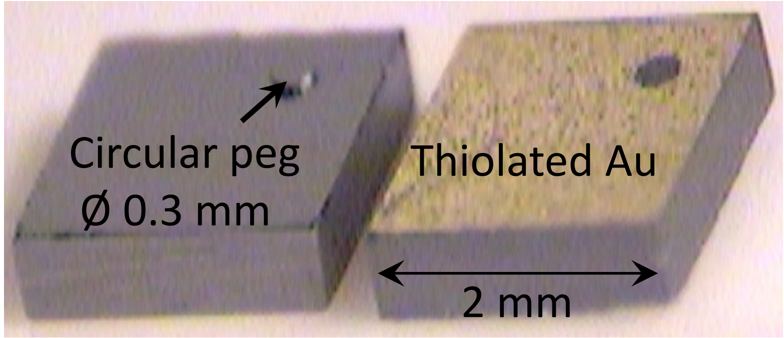
*164 silicon parts self-aligned on a 4-inch alignment template.*



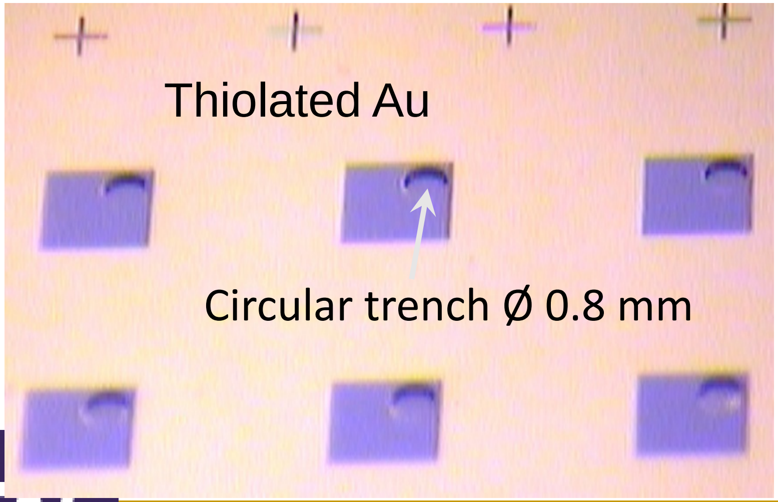

*Wafer level flip-chip bonding scheme for the mounting of uniquely aligned microchips onto a chip carrier template with electrical circuits.*

# Parts & Receptor Sites

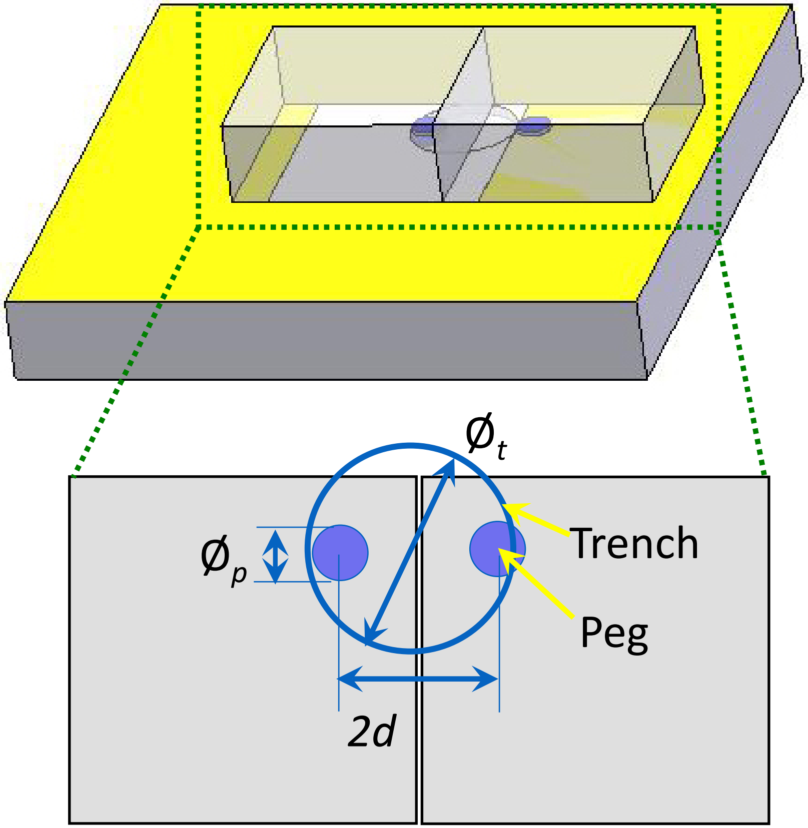
Top and bottom views of part




Array of receptor sites



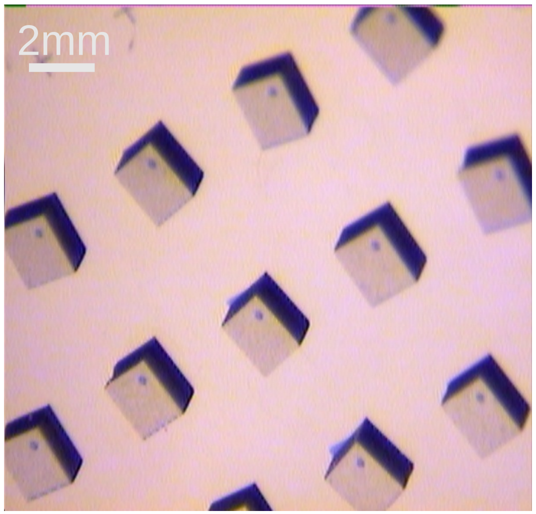

Design rule for one-to-one registration




$Ø_t < Ø_p + 2d$

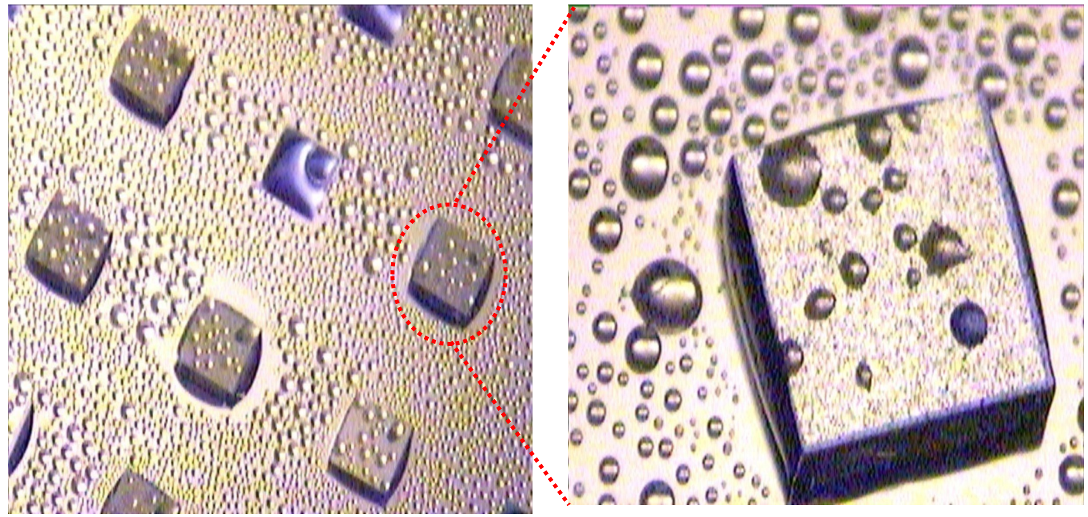
# Two-Step Alignment

**Step I**

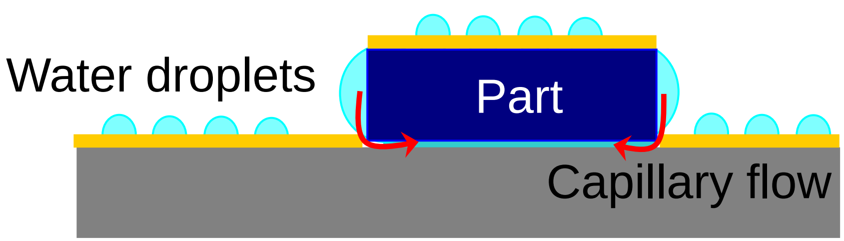



Gravity driven alignment

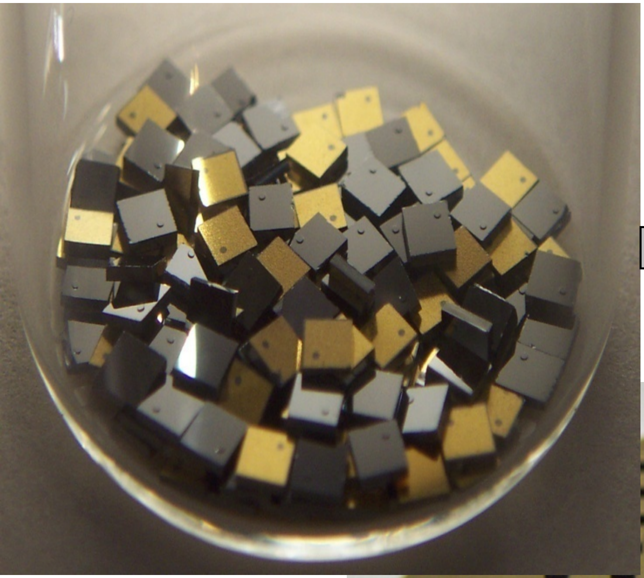
**Step II**



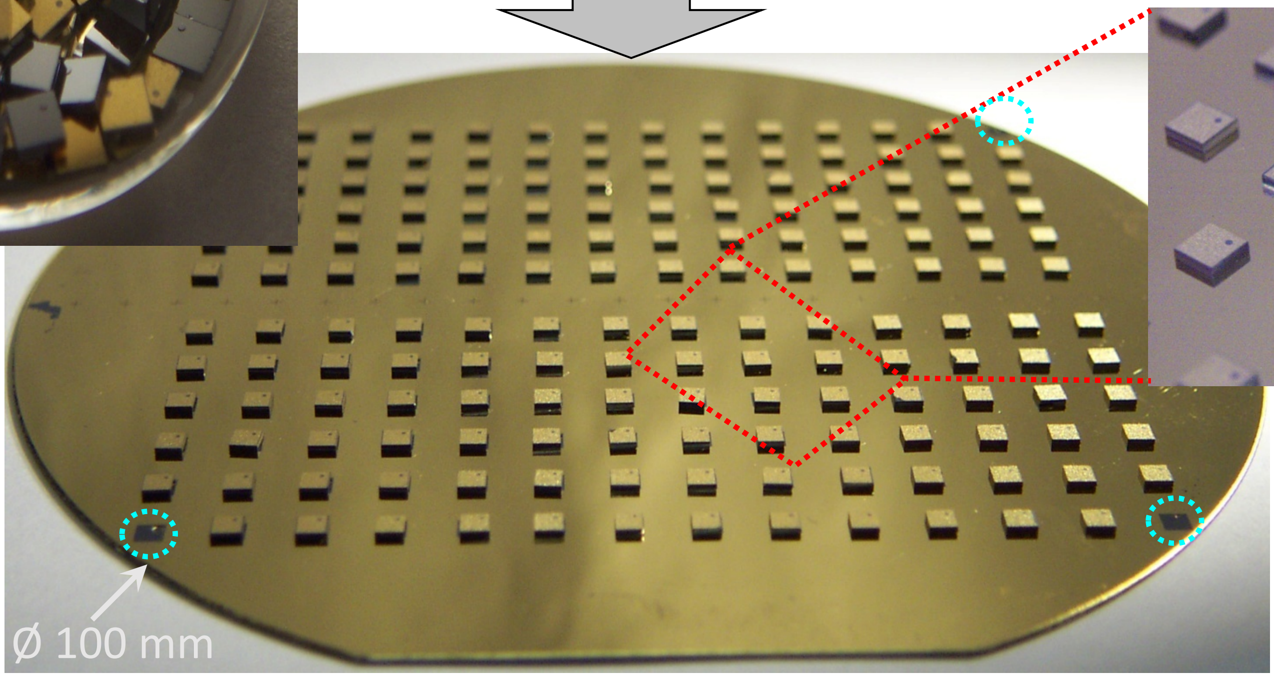
Capillary force driven alignment with water steam

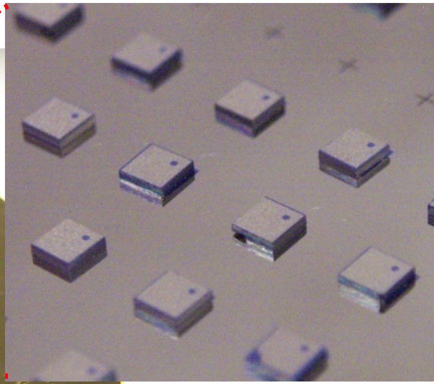


# Uniquely Orienting Self-assembly

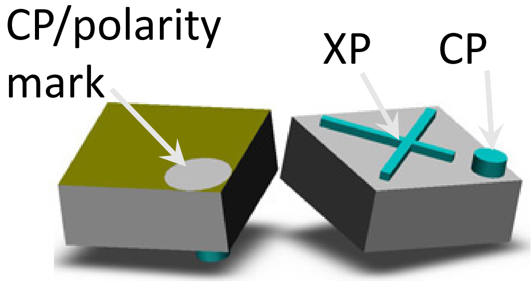


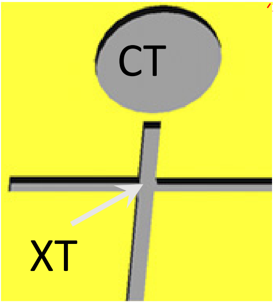
164 silicon parts (2 mm square) assembled on a 4-inch template [J. Fang et al. *JMEMS ‘06*]



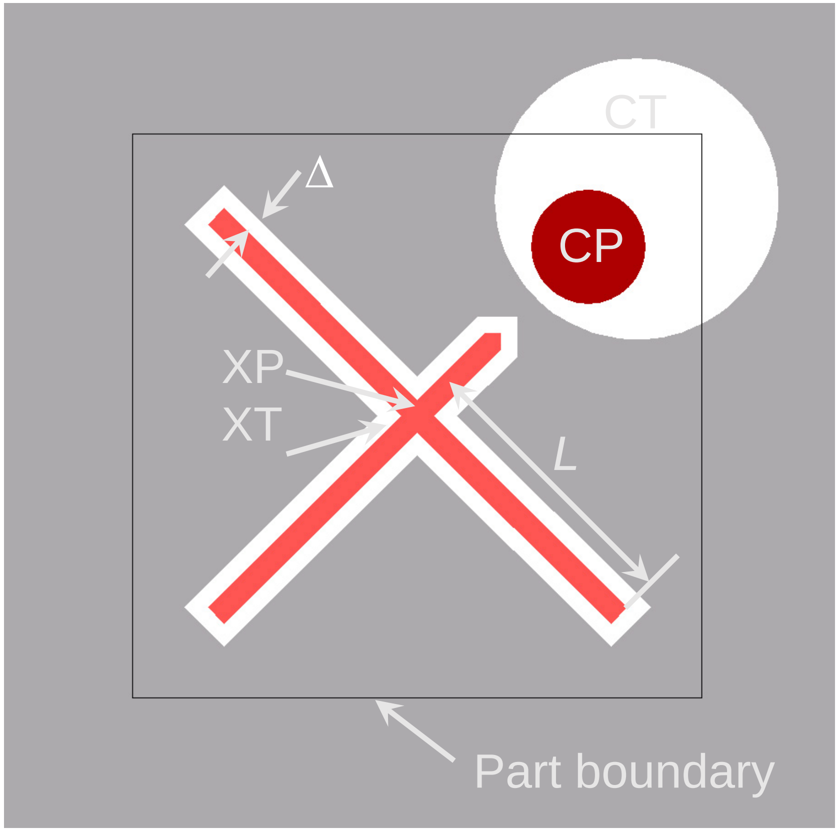
# Dry Self-Assembly with Unique Orientation



# Design Rules for Alignment Features

Exact alignment top-view layout

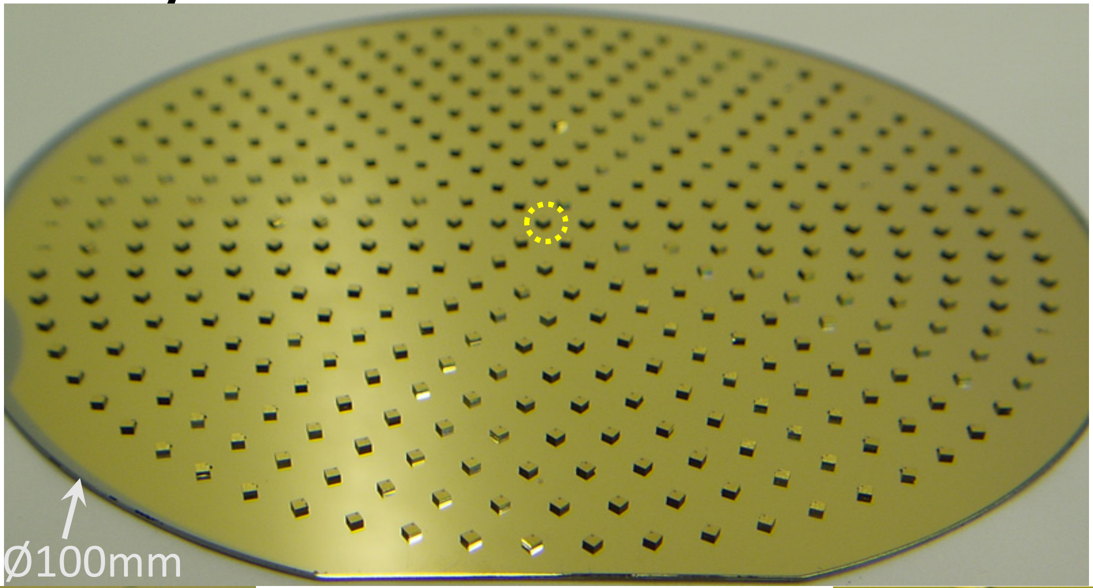



1. CT / XT exclusively adopts CP / XP
2. One CT adopts only one CP for one-to-one registration
3. Clearance Δ ~ 10-20 μm
4. Beam length *L* as long as possible to minimize rotational misalignment
5. Spacing between receptor sites large enough for neighboring parts to rotate about their CPs

**Maximum misalignments:**

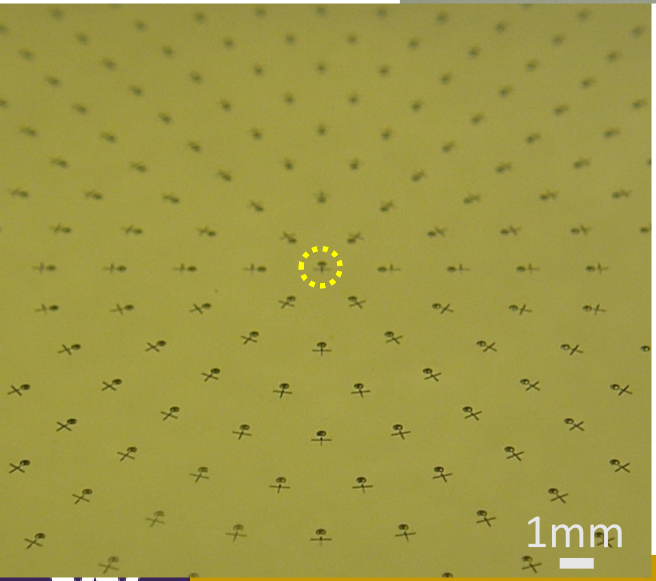
Translational = $\pm\Delta$, Rotational = $\tan^{-1}(\Delta/L)$

# Assembly Result I




Polar array of receptor sites

▽



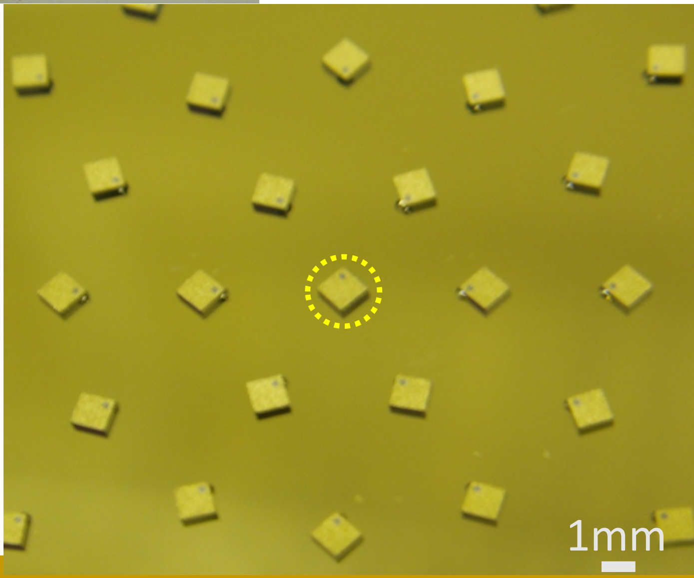

△

388 parts assembled on a 4-inch ALT with 397 receptor sites after 10 minutes agitation (Yield = 97.7%)

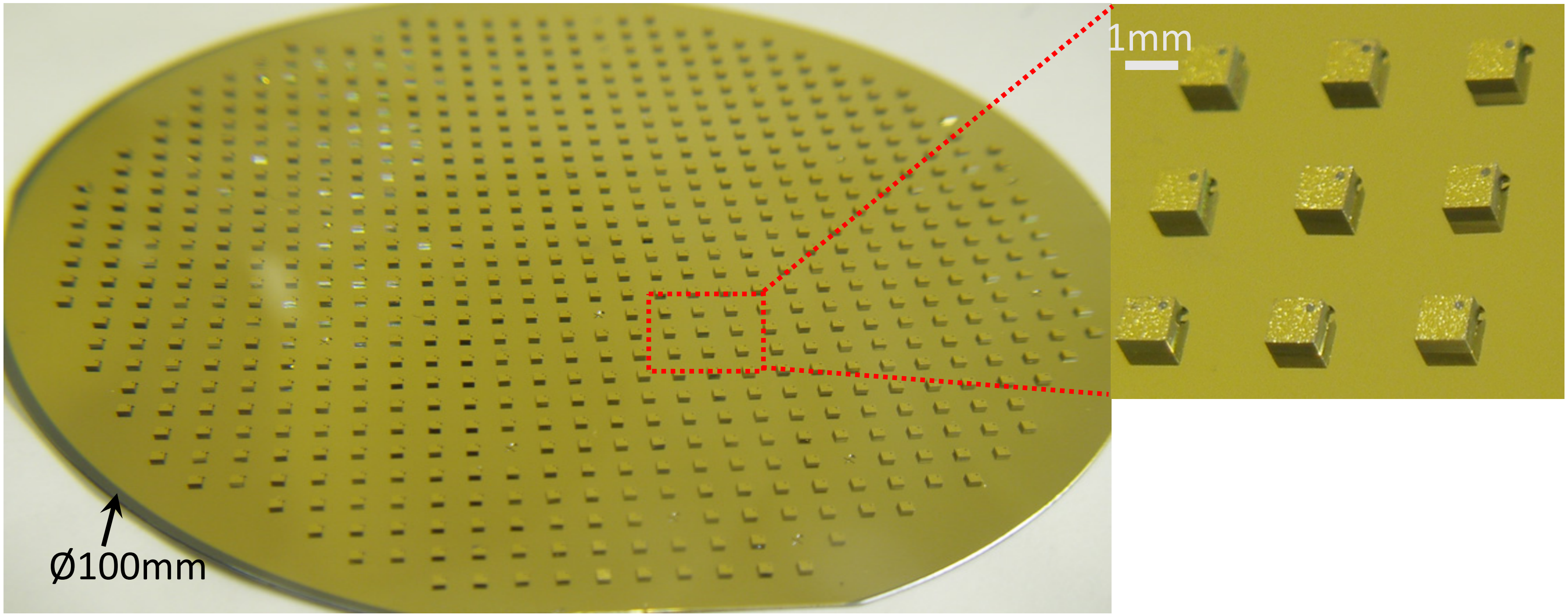
(Part redundancy = 50%)

ALT center parts

▽



# Assembly Result II

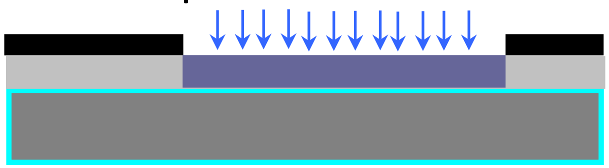



710 parts assembled on a 4-inch ALT with 720 receptor sites after 10 minutes agitation (Part redundancy = 50%)
(Yield = 98.6%)

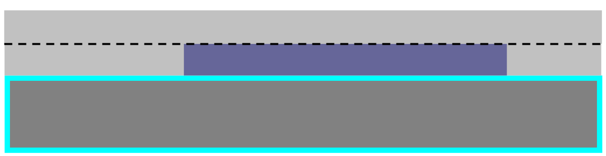
# Application to Non-Silicon Parts

I. Spincoat 1st layer SU8

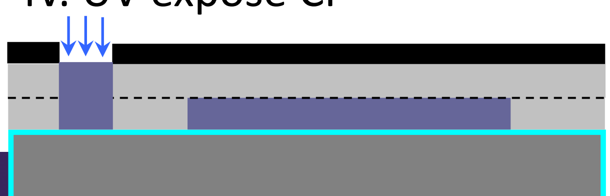

II. UV expose XP



III. Spincoat 2nd layer SU8

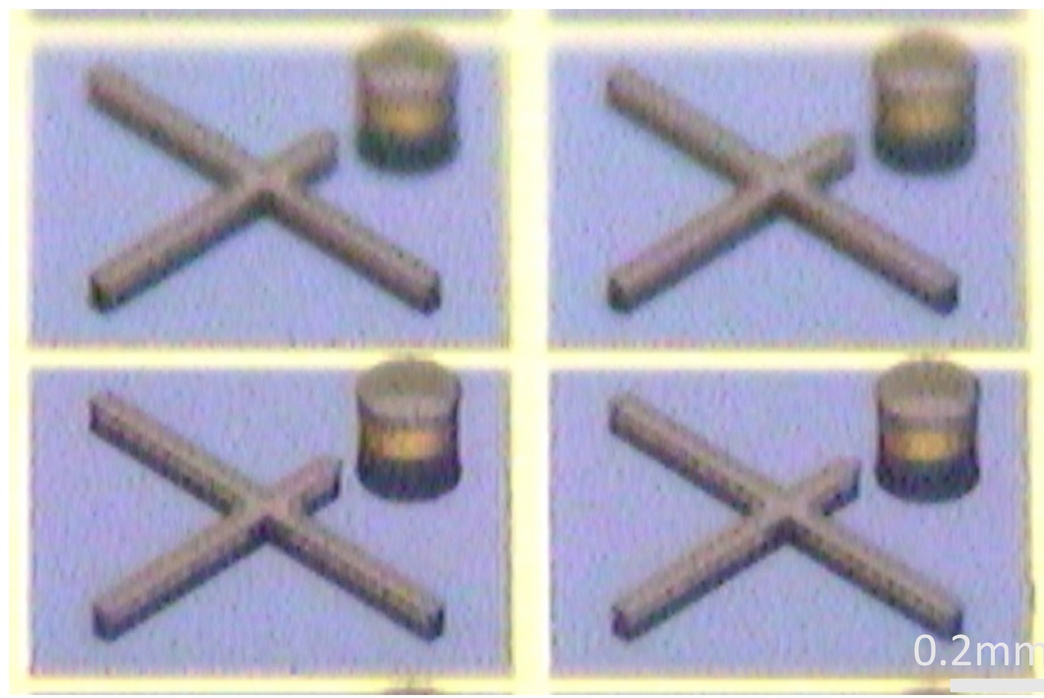


IV. UV expose CP

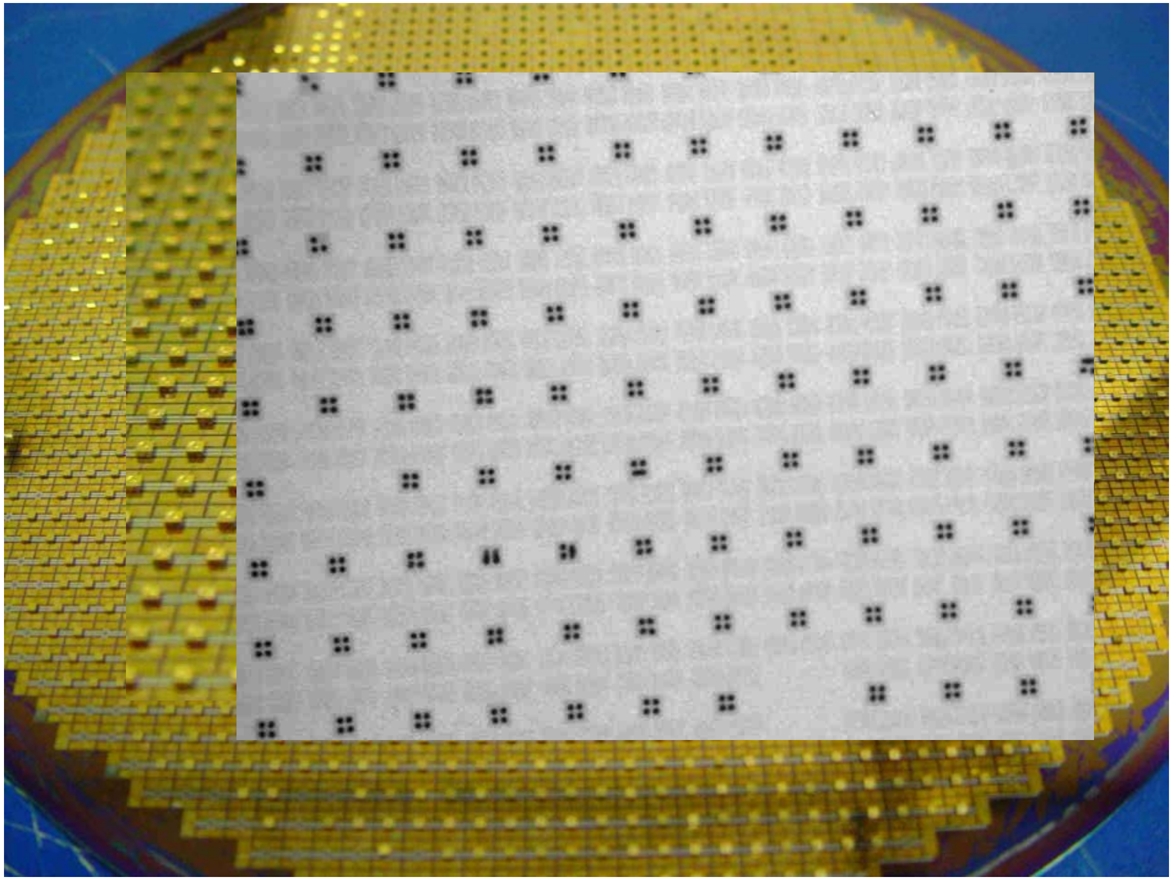


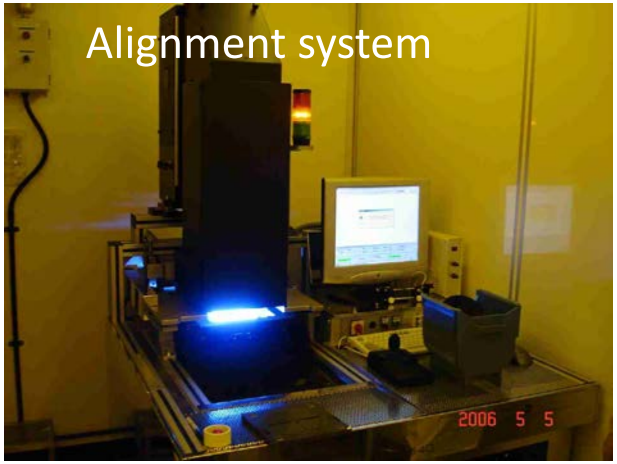
V. SU8 developed

Alignment features fabricated with SU8-2025



# Industrial-scale Self-assembly







Self-assembly and bonding of chips on 8” wafer
( collaboration with ASTAR IME, Singapore)