MICRO-331
Microfabrication technologies

J. Brugger
M. Gijs
& teams

Micro for nano Part III

Remember E-beam lithography

EBL: basic concepts

- Why use electrons instead of photons?
  - Overcome the optical diffraction limit
  - Electron wavelength, De Broglie equation

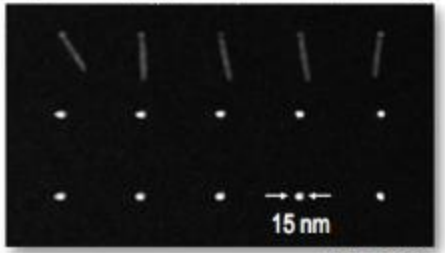
kV	1	10	100
nm	0.038	0.012	0.0038

  - sub-20 nm features feasible
  - Writing tool for UV/DUV masks
- What are the «cons»?
  - Expensive
  - Slow when compared to projection lithography systems

SEM image of two layer lithography with negative resist (HSQ)

V. Flaubaud - EPFL

Negative resist (HSQ) pillars 15 nm diameter, 150nm height

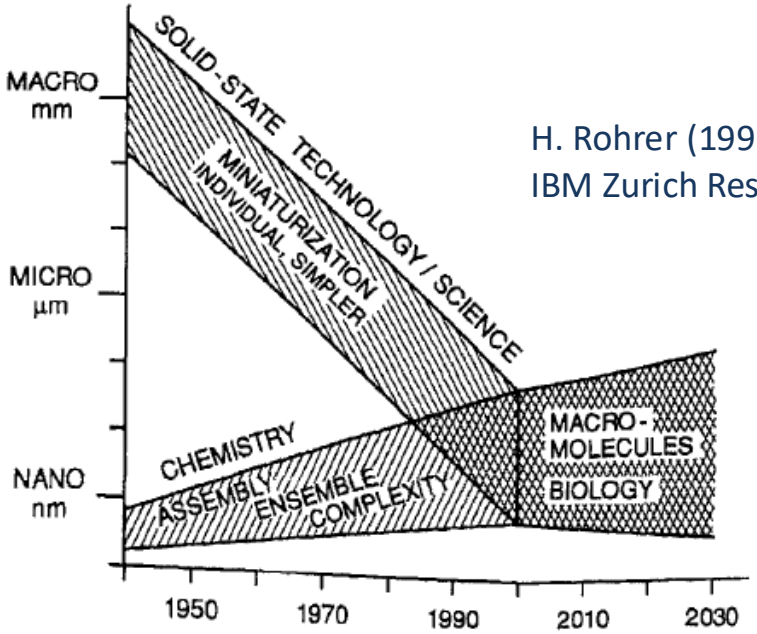


V. Flaubaud - EPFL

Bottom-up versus top-down fabrication

- Top down
  - From a design to the writing of a pattern
  - Laser writer, focused electron beam writer, focused ion beam, scanning probe lithography
  - Pro: flexible; Disadvantage: slow
- Bottom up
  - Self-organisation, self-assembly
  - By natural forces; always looking for the energy minima
  - Pro: scalable in size of objects and surfaces to engineer; disadvantage: deterministic control on position
- Combine top down and bottom up
  - Templated self-assembly

The Top-Down meets Bottom-Up vision



H. Rohrer (1992)
IBM Zurich Research

STM: 10 years after, *Ultramicroscopy* 42-44 (1992)
The nanoworld: Changes and challenges, *Microelectronic Engineering* 32 (1996) 5-14

Building a system

supervised assembly

… so, what is self-assembly?

- “The autonomous and spontaneous organization of components into patterns and structures”
  G. M. Whitesides

- “The science of things that put themselves together”
  J. Pelesko

- “A scalable manufacturing method for heterogeneous integrated systems”
  K. F. Böhringer

- “Self-assembly is embodied in all sets of components that can be put together through appropriate shaking”

Building by Self-Assembly

SA

Self-organized formation of higher-order structures
from pre-existing parts, which is adjustable and controllable
by the design of components, environment and forces

Whitesides & Grzybowski, *Science* 2002

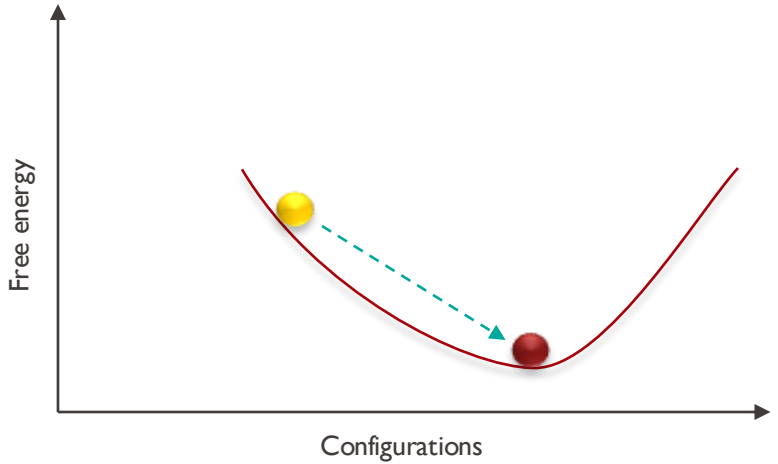
Thermodynamics

$$\Delta G = \Delta H - T\Delta S$$

G = **free energy**
H = **enthalpy**
- bonds

T = **temperature**
- agitation

S = **entropy**
- configurations



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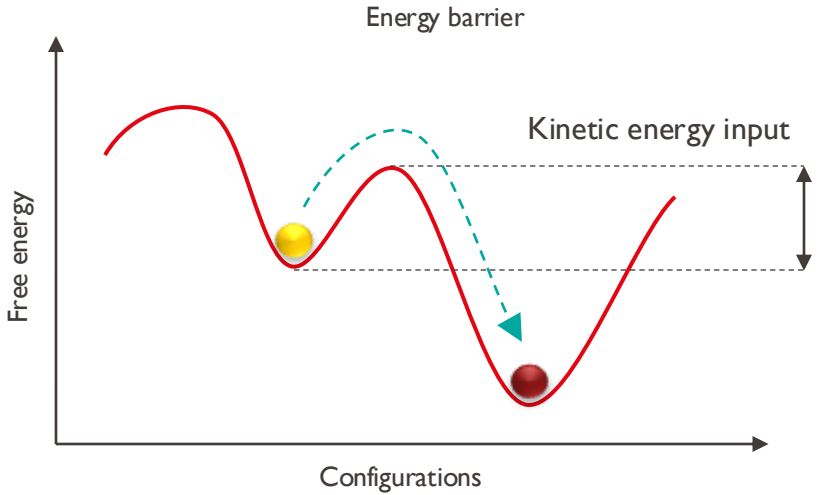
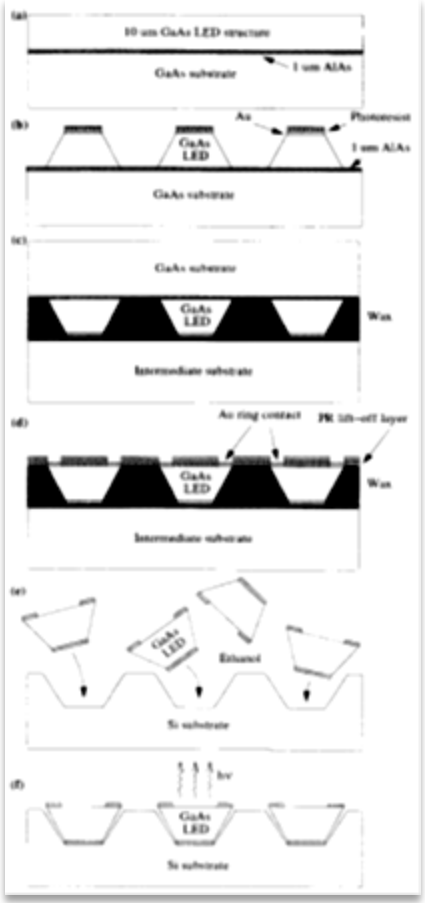
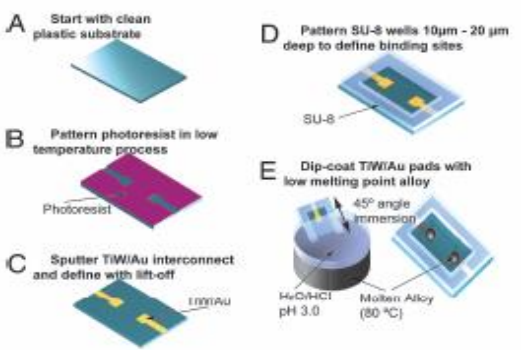


Fluidic self-assembly (FSA)

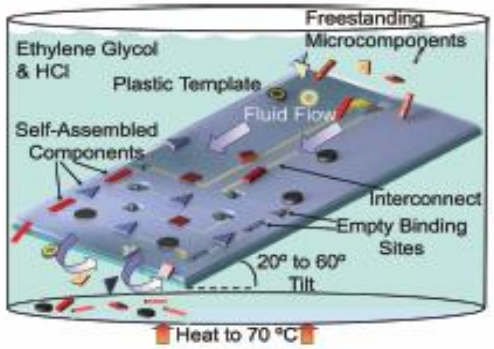
- First publication in 1994
  - H.-J. J. Yeh, J. S. Smith, “Fluidic Self-assembly of Microstructures and its Application to the Integration of GaAs on Si”, *IEEE MEMS*, 1994
- Ingredients
  - Receptors anisotropically etched in Si or molded plastic substrates
  - GaAs components with matching shapes
  - Post-processing for interconnections
- Patented in 1996:
  - Smith, Yeh, *Method for fabricating self-aligned microstructures*, US Patent 5,545,291



Fluidic self-assembly

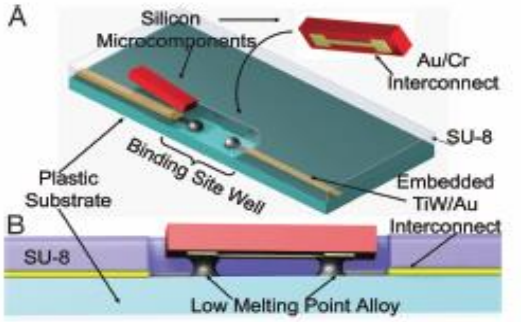


Substrate processing



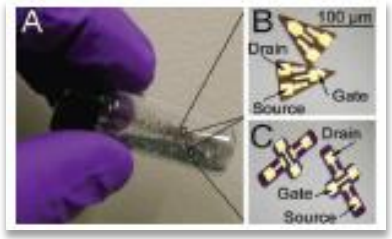
- Grooves made by SU8 patterning
- Bonding by low-mp solder

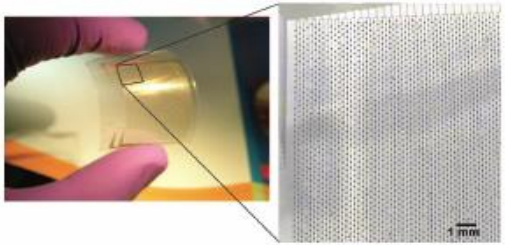
Gravity & solder-driven assembly



Stauth & Parviz, *PNAS* 2006

Single-crystal silicon FETs





~10000 assembled chips in 25 minutes (not automated), 97% yield

Templated nano-assembly

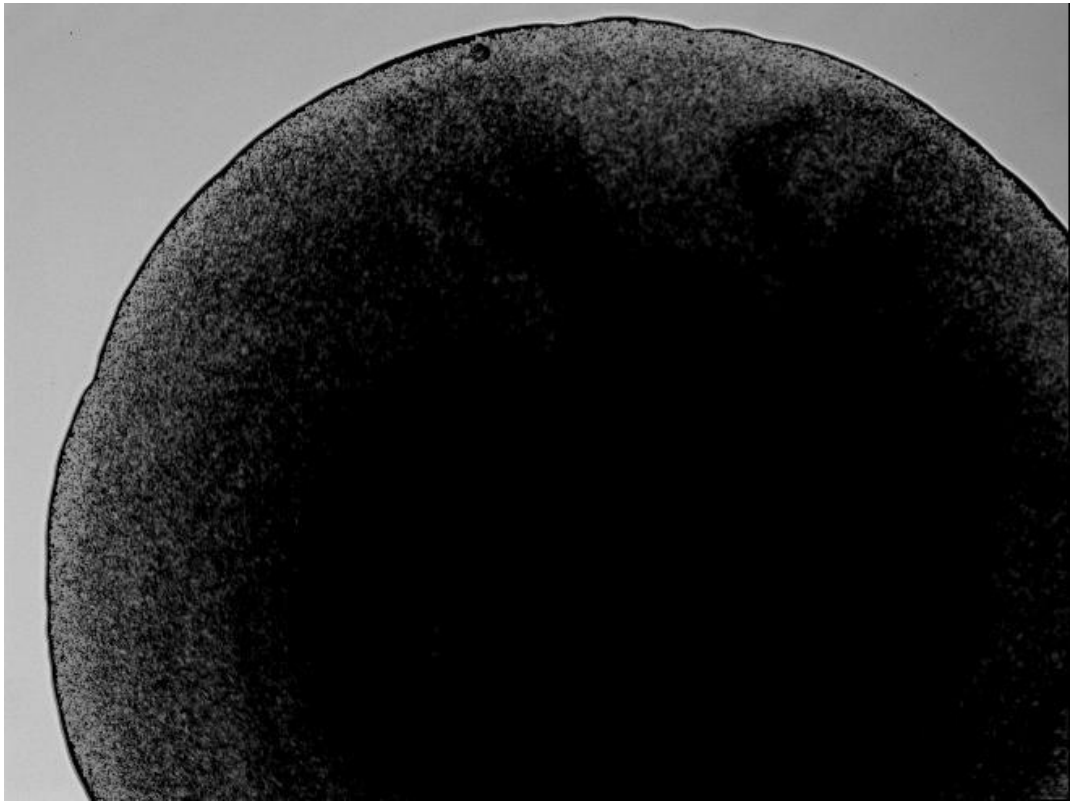
Capillary assembly of nanoparticles

Challenges to control

- Position (template traps)
- Orientation (template traps)
- Interparticle gap (surface functionalization)
- Yield on larger area (process control)

- E-beam lithography
- Dry/wet etching
- Temperature, humidity, speed, colloidal suspension

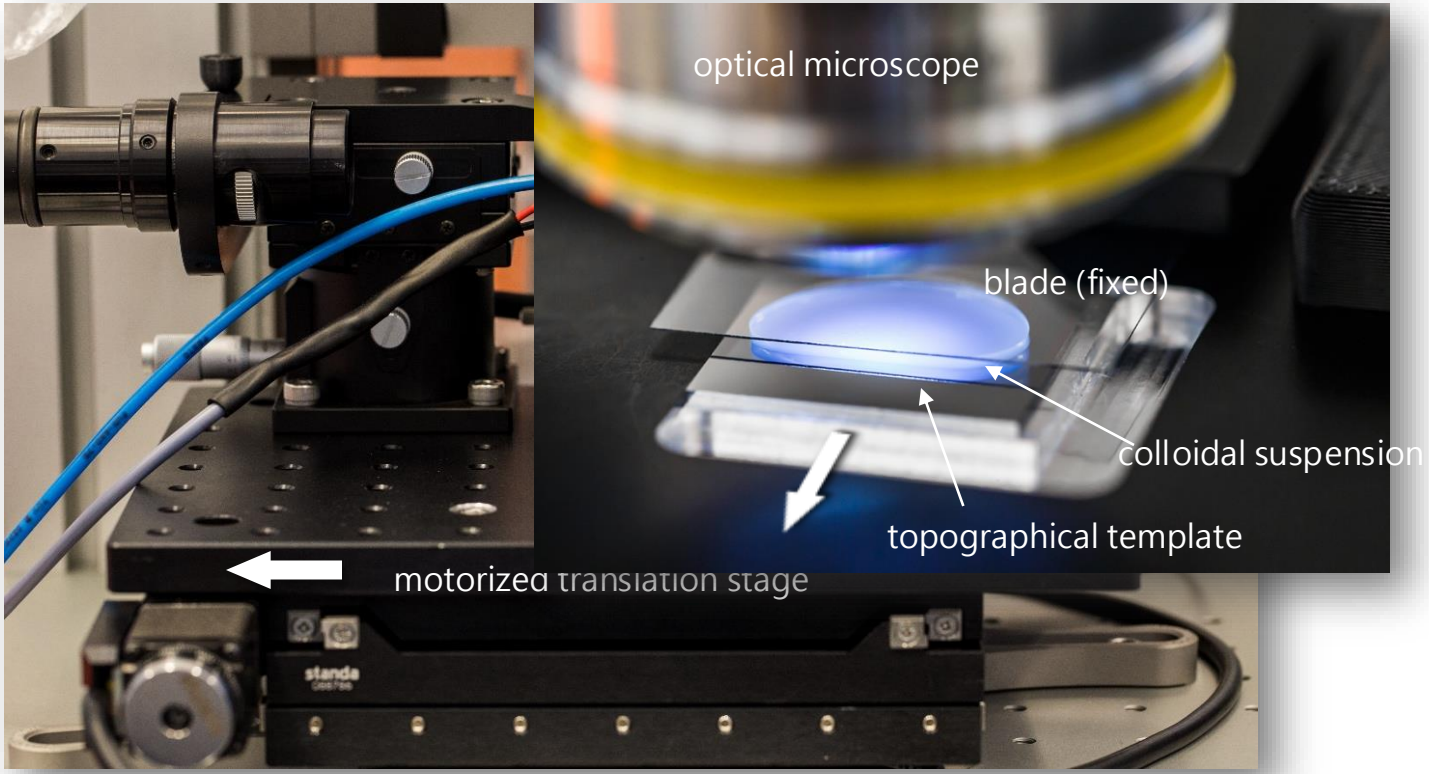
Bottom-up nano-assembly



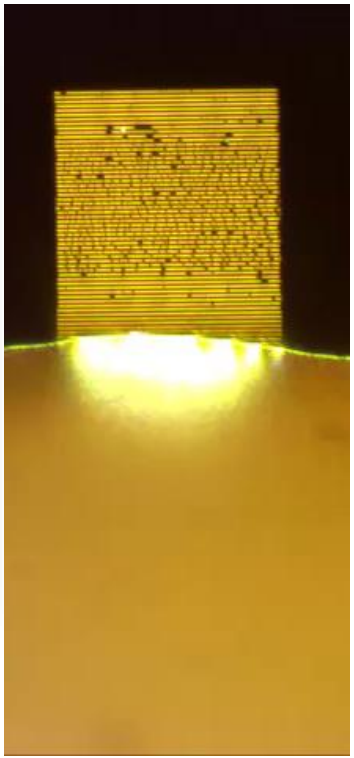
Still *et al.*, *Langmuir* 2012

Nanoparticle blade coating

Juergen Brugger

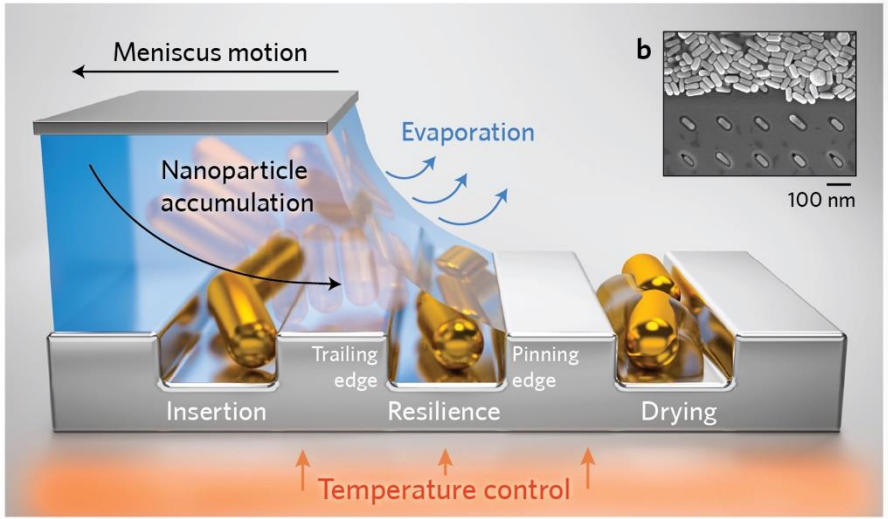


Top view

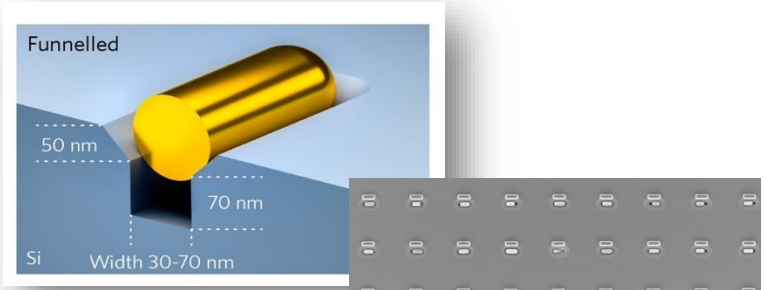


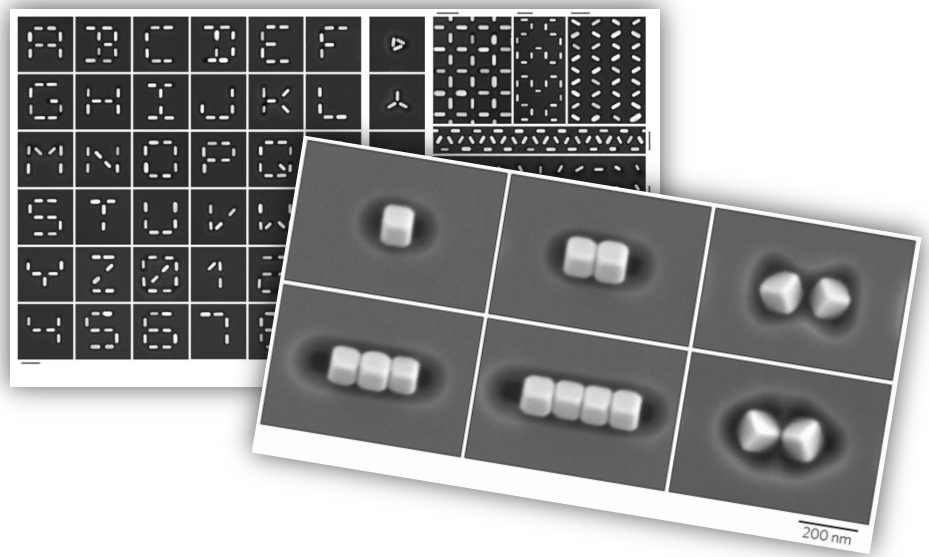
Control of meniscus is key

Capillary assembly

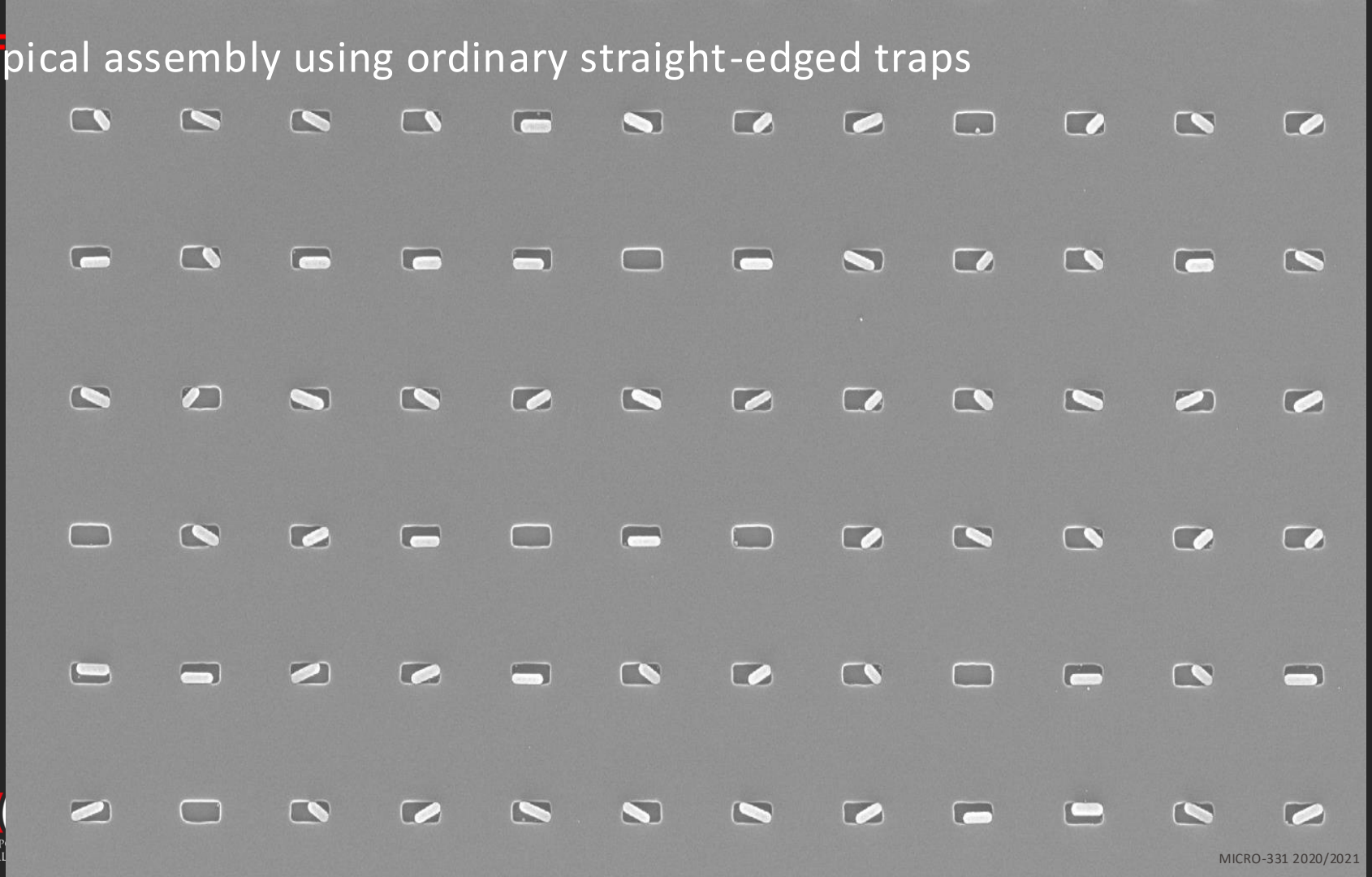


Nat. Nanotechnol. 2017

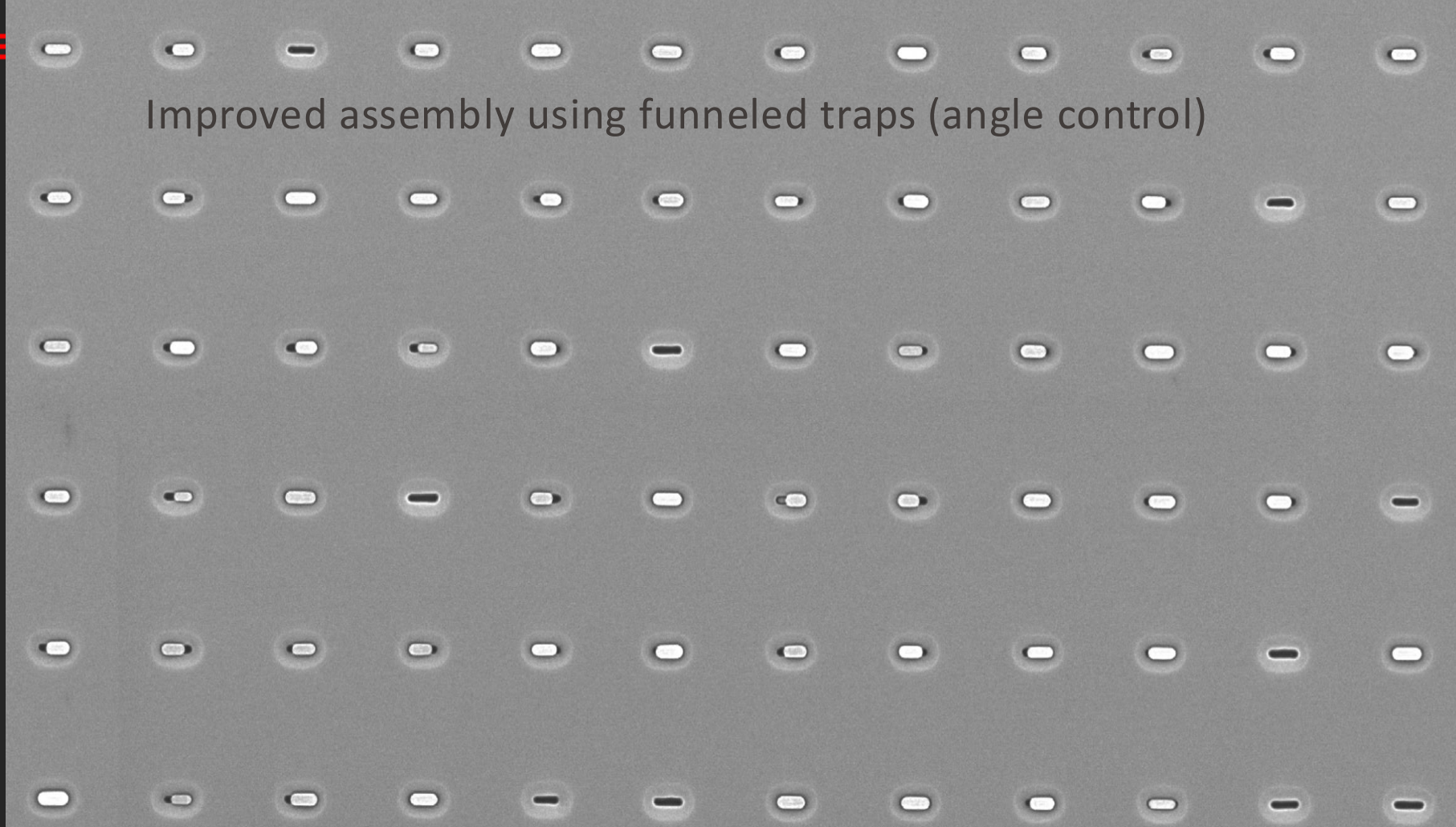




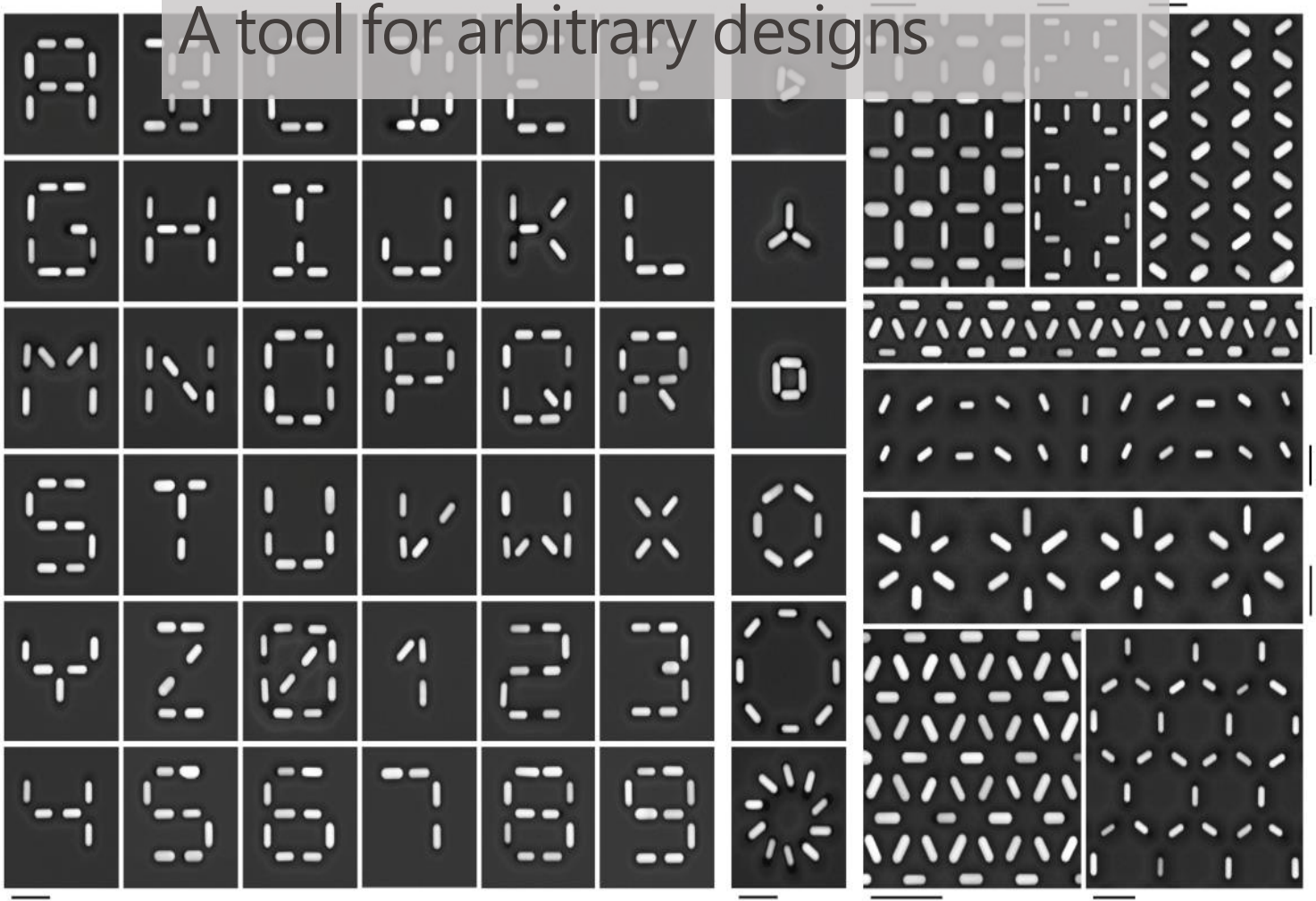
Typical assembly using ordinary straight-edged traps



Improved assembly using funneled traps (angle control)



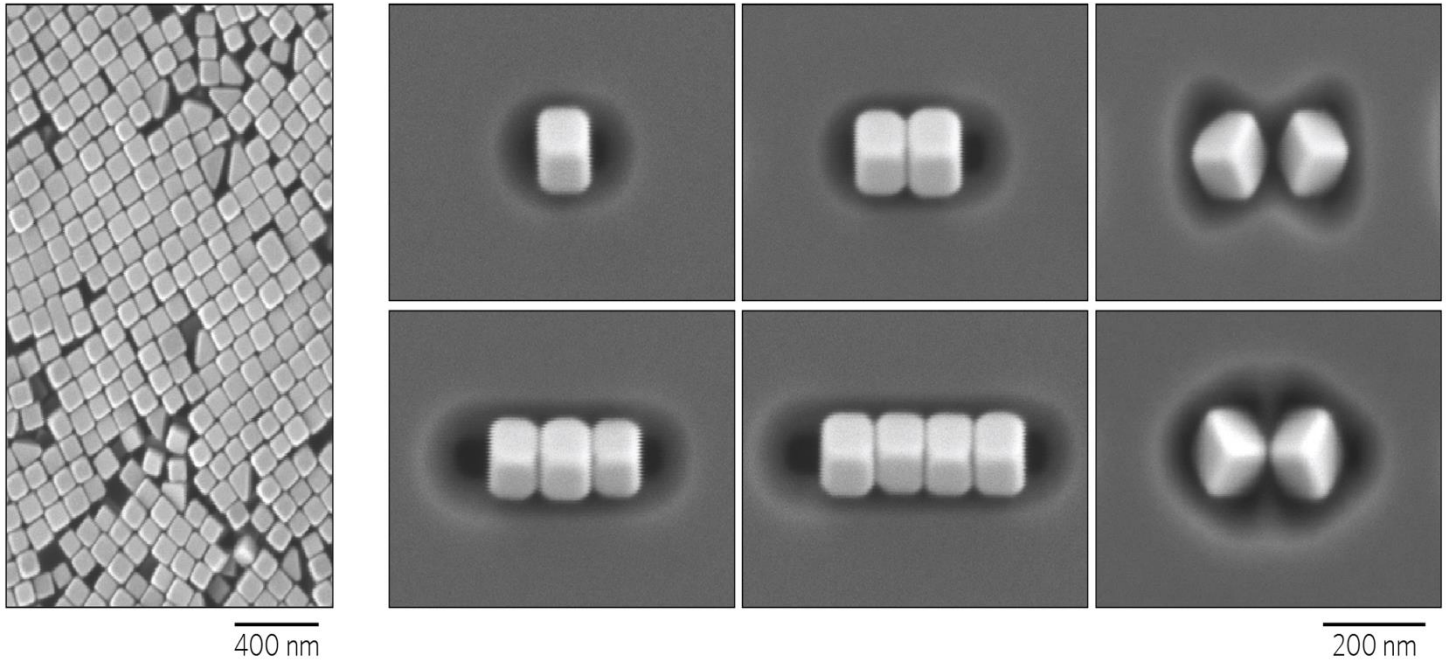
A tool for arbitrary designs



V. Flauraud *et al.*, *Nat. Nanotechnol.* 2017

Scalebars: 250 nm

3D orientation of Ag nanocubes



V. Flauraud *et al.*, *Nat. Nanotechnol.* 2017

Things are different at nanoscale

Nano (gr) = nain (fr)

Nanoscale MEMS or NEMS

- What is different when going from micro to nanoscale?
- Nanoparticles (0D), nanowires (1D), nanoflakes (2D)
- New functionality of devices that are unique to the nanoscale size
- Nanoscale imaging by scanning probe microscopy (=nano-MEMS)
- Microfabrication of nanotips
- Nanoscale fabrication (top down)
- Nanoscale fabrication (bottom up)