Functional Mesoscale Systems: Opportunities for Space-Based Self-assembly

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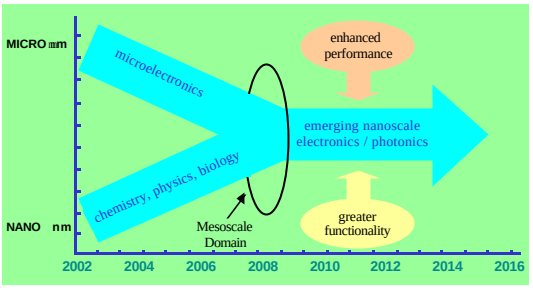
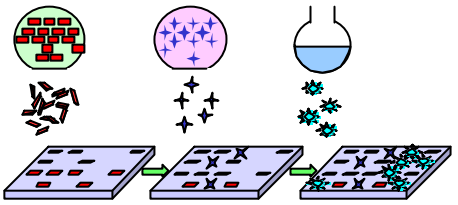
Nanoscale Science and Technology



Functional Mesoscale Objects

- Length Scales:
  - 10 nm — 100 µm
- Types:
  - Supermolecules, Polymers
  - Biological molecules / cells
  - Nanocrystals, Nanotubes, Nanowires
  - RTDs, LEDs, MEMS, MOEMs.
- Broad applications:
  - Catalysis, Energy Storage,
  - Diagnostics, Discovery,
  - Information Processing, Communications.

Assembly of Functional Mesoscale Systems



HYBRID mesoscale systems must be INTEGRATED at low density using appropriate assembly methods

Heterogeneous Integrated Functional Mesoscale Systems

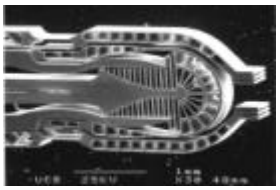
- Photonic integrated circuits
- Planar lightwave circuits
- Displays
- Imaging arrays
- MOEMS
- RF integrated circuits
- RF MEMS
- Integrated chemical and biological sensor arrays
- Hybrid (molecular) nanoelectronic devices

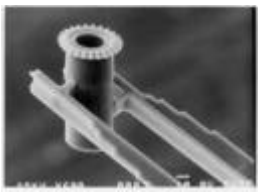
Serial Assembly: Commercial Aligner-bonder

- Placement accuracy 1.5 to 3 µm.
- 60 chips max. per hour @ bonding temperature of 250-350°C approx.
- Cost 400K to 800k€.
- Component min. size 200 µm.
- Operator training.
- Labour intensive.

SUSS MicroTec

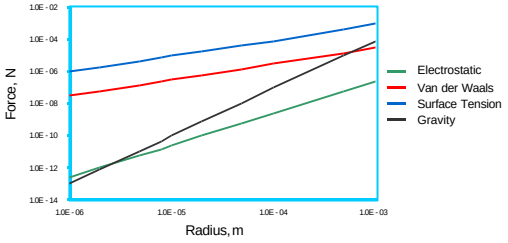
Serial Assembly: Silicon Micro Tweezers



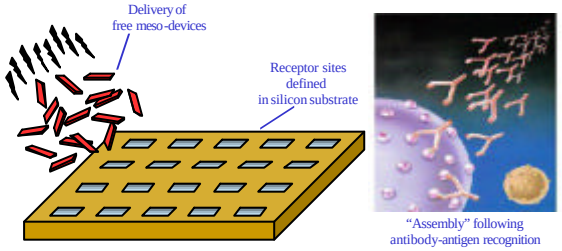


C. Keller at Berkeley / MEMS Precision Instruments

Component Release: Adhesion V's Gravity



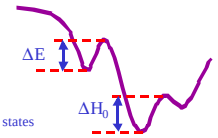
Self-assembly ?



"Assembly" following
antibody-antigen recognition

Physical analogy of naturally occuring biological process?

Simple Model for Self-assembly

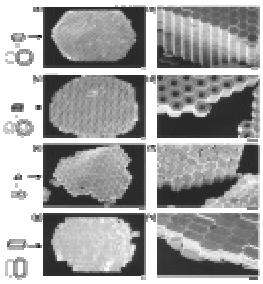


Requirements for assembly:

- Target configuration is global minimum of system
- ⇒ Sufficient driving potential, ΔH_0, w.r.t. all other states
- Source of random kinetic energy, ΔE, to escape local minima
- ⇒ Use annealing processes to reach global minimum
- Assembly time at a receptor site, $t \propto \exp(|\Delta E / \Delta H_0|)$

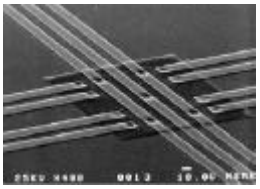
Biomimetic Self-assembly Driven by Capillary Forces

G. M. Whitesides



Fluidic Self-assembly

70 and 185 micron NanoBlocks

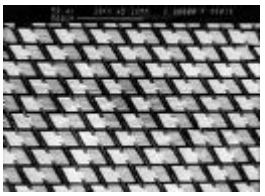


Interconnected assembled NanoBlock

Specifically shaped devices are flowed (in water) over substrate with matching holes (receptors) into which the components eventually settle - Alien Technology.

Manipulator Surfaces

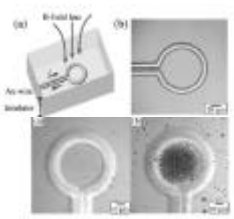
Polyimide cilia motion pixel with four actuators in a common centre configuration.
J. W. Suh, G. T. A. Kovacs



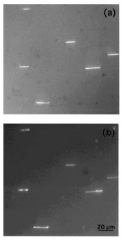
Microfabricated single crystal silicon torsional resonator array.
Karl Böhringer, Noel McDonald

Massively-parallel, microfabricated actuator arrays allow sensorless manipulation (e.g., parts-translation, -rotation, -orientation, and -centering).

Magnetic Assembly

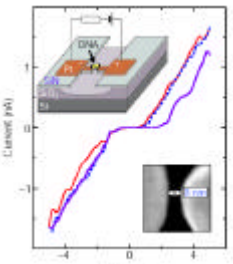


R.M. Westervelt

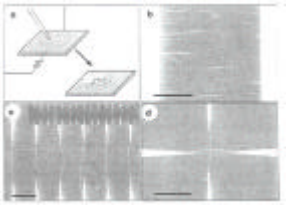


G.J. Meyer

Electrostatic Self-assembly

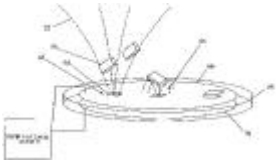


C. Dekker

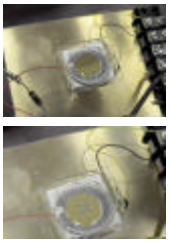


C. M. Lieber

Electrostatic Self-assembly

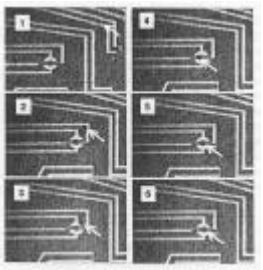


- Parallel plate capacitor with patterned holes (defined binding sites).
- Parts are attracted in electrostatic fringing fields.
- Vibratory annealing to energy minimum.
- M. Cohn US Patent.

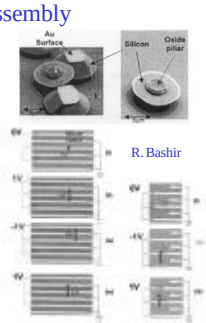


Positioning of four surface mount capacitors.
Trapping voltage in air 3kV; in vacuo 300 V.

Electrostatic Self-assembly



M. J. Heller / Nanogen

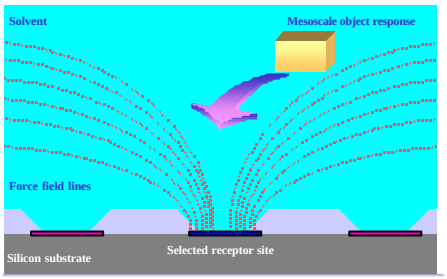


R. Bashir

Ideal Approach: Force Field Directed Assembly

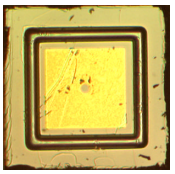
- "Hands-free" programmable force field method
- Component manipulation and assembly on-chip
- Serial or massively parallel implementations
- Assembly of sparse or dense arrays of components
- High-throughput & integration-compatible process

Our Field Configurable Assembly Concept



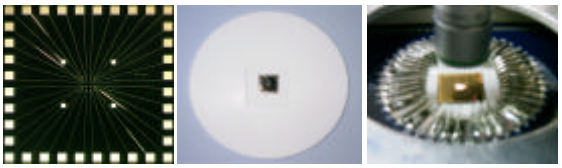
Model Mesoscale Devices

SEM image an 80 µm diameter 850 nm emission LED of 10 µm thickness.



Optical micrograph of a 250 µm side VCSELof 100 µm thickness. The light emitting cavity is clearly visible in the centre of the device.

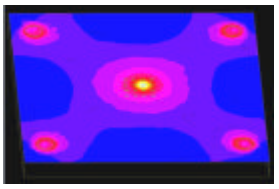
Receptor Array on Silicon Chip



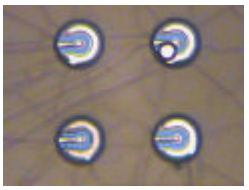
Microfabricated Si chip substrate with n x n receptor electrode array.

Teflon holder and probe card specifically designed for addressing of receptor electrodes.

Field Configured Serial Assembly

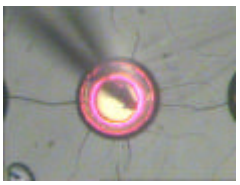


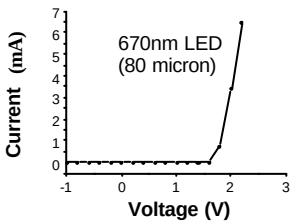
Electric field distribution around an individually addressed receptor electrode.



Component transport by sequential addressing. (50 µm diameter 670 nm emitting GaAs LED.)

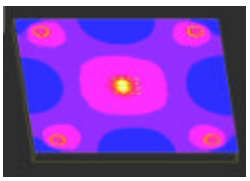
Light Emission Following Bonding

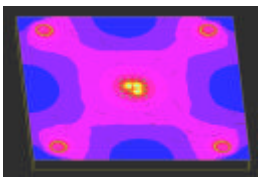




670nm LED emission following successful transport, reflow and probing/integration.

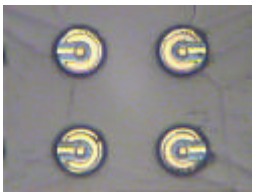
Field Configured Parallel Assembly

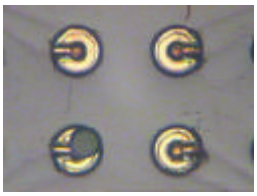




Field distributions around neighbouring receptor electrodes bias ed simultaneously.

Field Configured Parallel Assembly

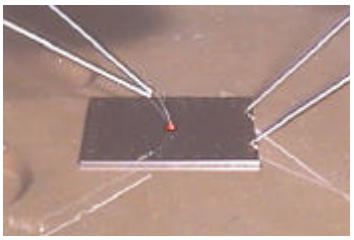




Component assembly by parallel addressing. (80 µm diameter 670 nm emitting GaAs LEDs.)

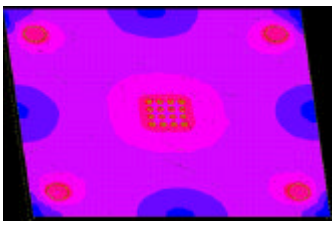
Component assembly by sequential / parallel addressing. (50 and 80 µm diameter 670 nm emitting GaAs LEDs.)

670 nm Emission



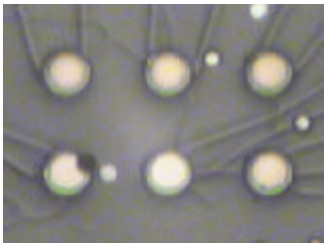
Light emission following successful transport, reflow and probing of the two devices.

FCA of Component Arrays



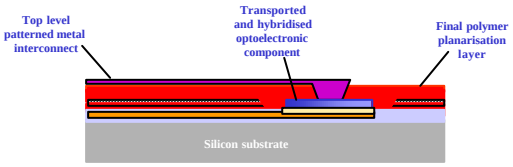
Full 4x4 receptor array parallel addressed versus corner counter electrodes.

FCA of Component Arrays



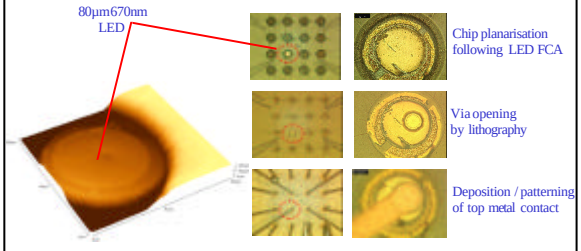
Component assembly by parallel addressing.
(50 µm diameter 670 nm emitting GaAs LEDs.)

Integration of Assembled Components

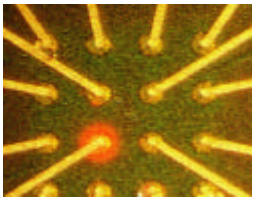


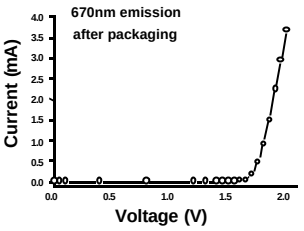
Collective wiring of components following FCA.

Planar Assembly and Collective Wiring



Interconnection and Light Emission





Summary

- Assembly / integration are recognised technology bottlenecks for fabrication of future functional mesoscale systems.
- Self-assembly approaches are being actively explored.
- Possible solution: Programmable force fields
  - Tweezer-less manipulation and assembly at chip or wafer level.
  - Serial or parallel implementations.
  - Assembly of sparse or dense arrays of different (un-modified) sub-100 micron devices.
  - High-throughput, post-process integration-compatible.
- Two key space-related opportunities:
  - Development of manufacturing methods for meso- & nano-subsystems.
  - Exploration of mesoscale assembly processes in μgravity environments.