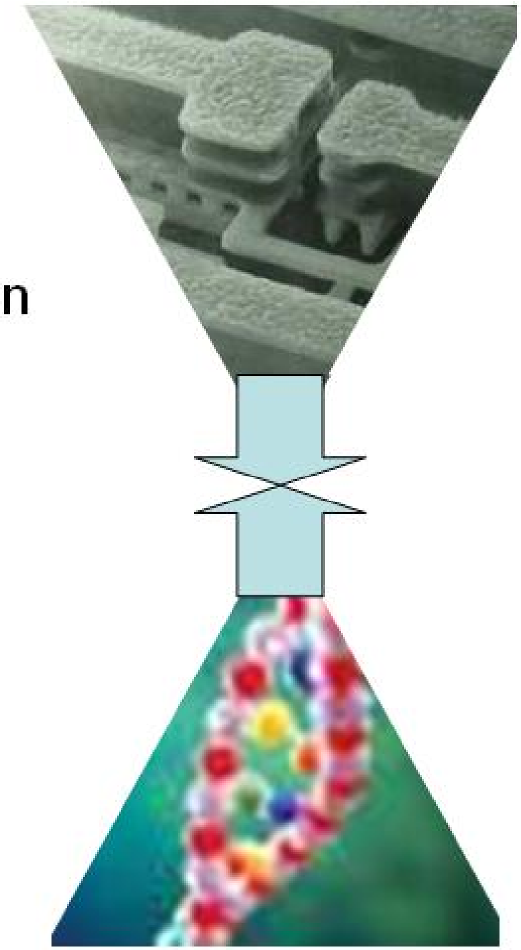
Lecture 3

Microscale Manufacturing Practices

Bottom up Approach

Top-down and Bottom-up Processes



lithography
&
microfabrication

chemistry
&
embryology

TOP-DOWN
FABRICATION

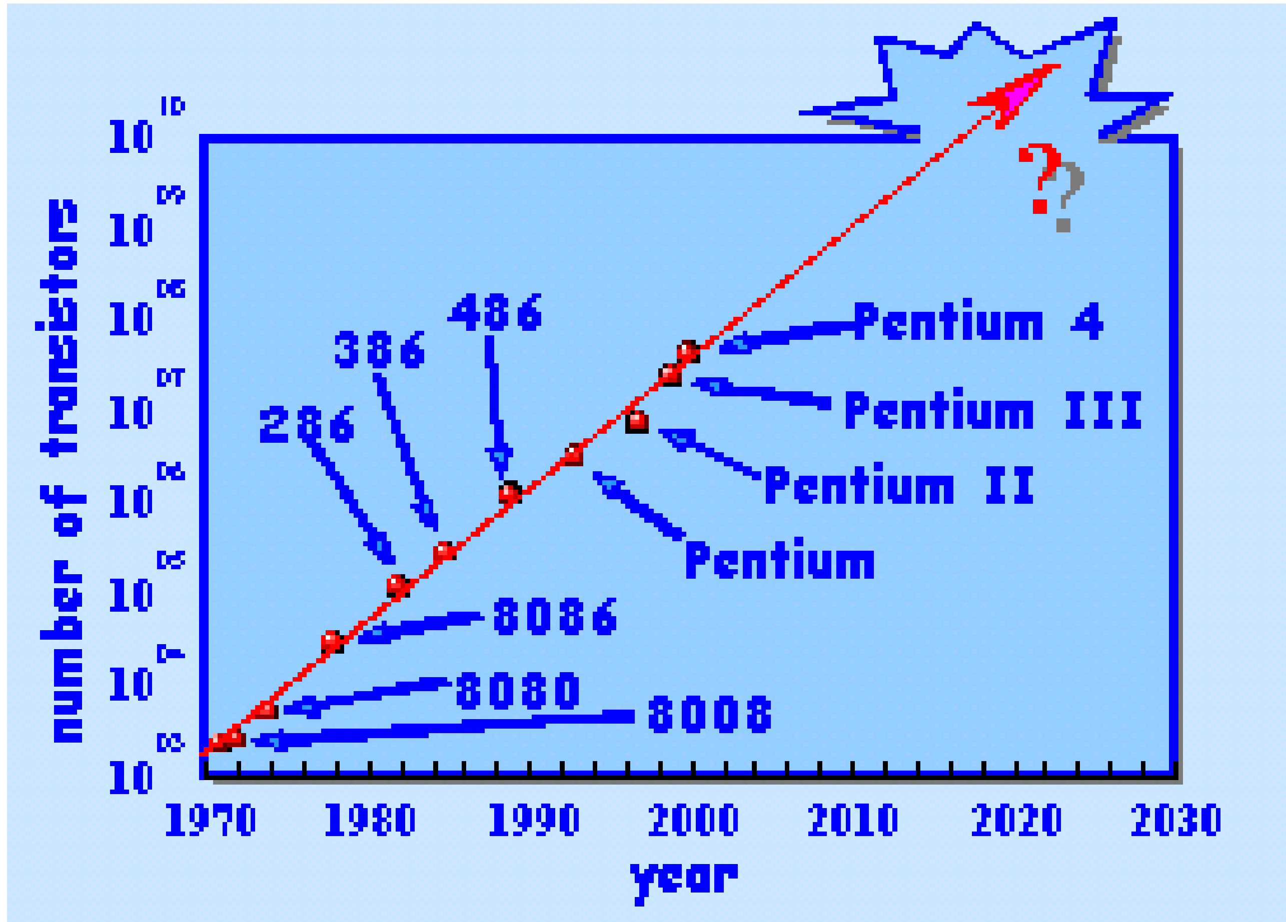
harder to perform
more expensive

harder to design
use self-assembly

BOTTOM-UP
FABRICATION

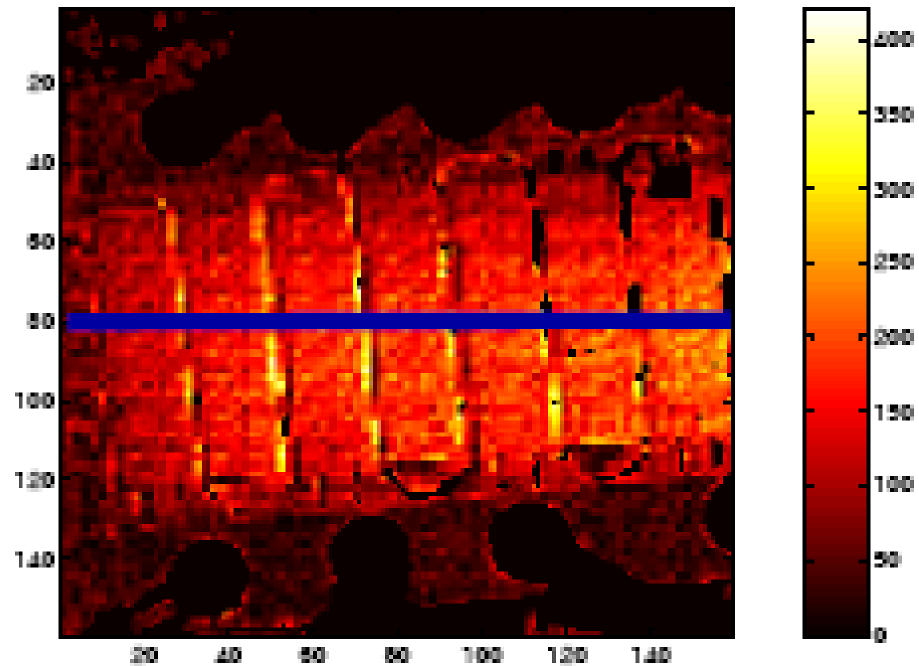
Problems of Top-down Process

- Cost of newer technologies.
- Physical limits of photolithography
- heat dissipation

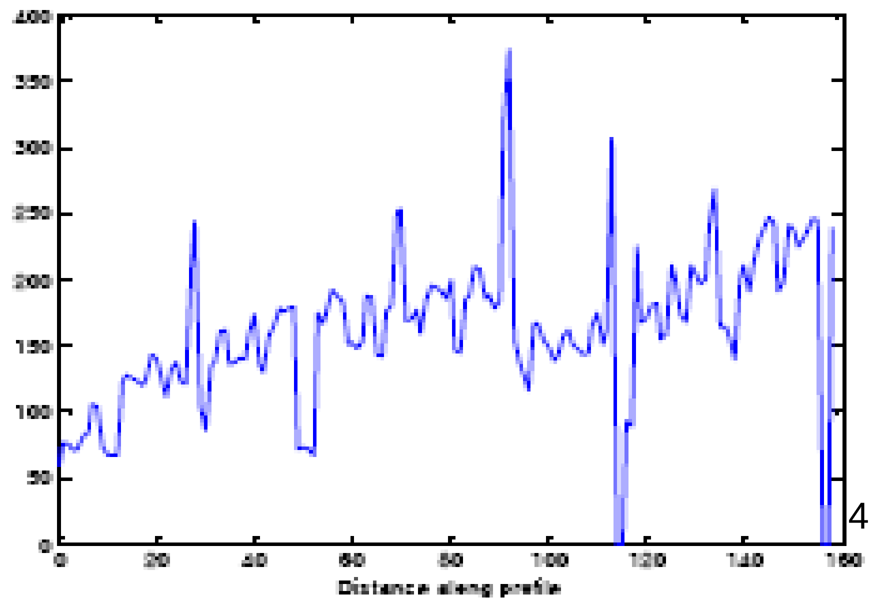


Heat buildup is becoming one of the major limitations to creating tomorrow's more compact, complex micro devices”.

David Benson of Sandia National Laboratory’s Advanced Packaging Department.

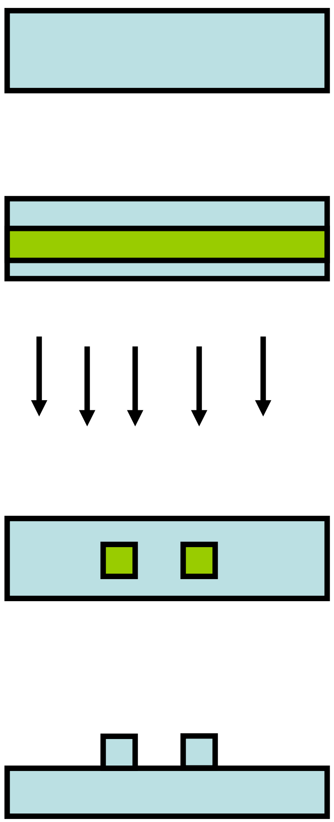


At 450 mA and 100 μs on time and 1 KHz frequency



Top-down Versus Bottom-up

Top Down Process



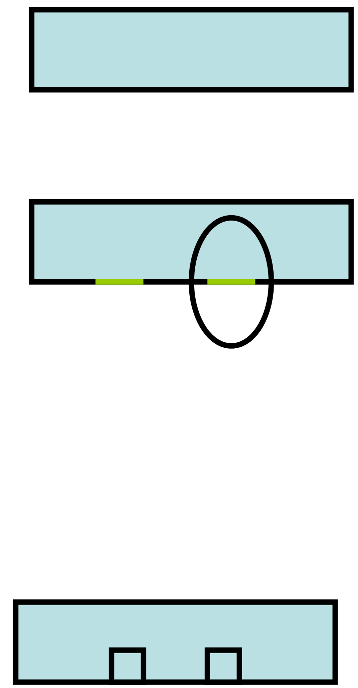
Start with bulk wafer

Apply layer of photoresist

Expose wafer with UV light through mask and etch wafer

Etched wafer with desired pattern

Bottom Up Process



Start with bulk wafer

Alter area of wafer where structure is to be created by adding polymer or seed crystals or other techniques.

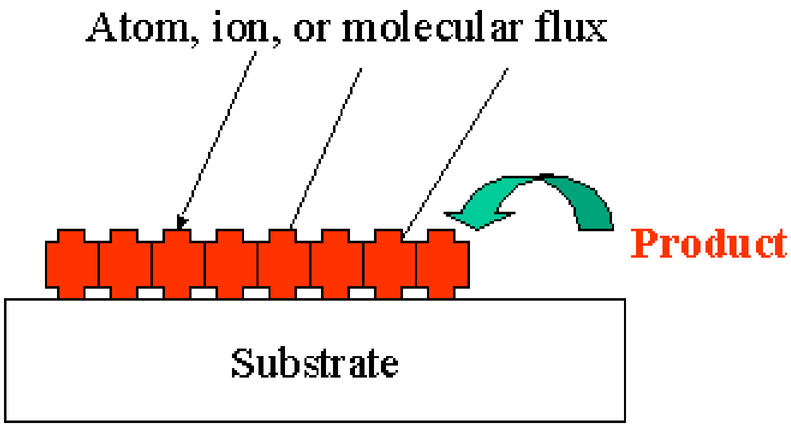
Grow or assemble the structure on the area determined by the seed crystals or polymer. (self assembly)

Similar results can be obtained through bottom-up and top-down processes

Why is Bottom-Up Processing Needed?

- Allows smaller geometries than photolithography.
- Certain structures such as Carbon Nanotubes and Si nanowires are grown through a bottom-up process.
- New technologies such as organic semiconductors employ bottom-up processes to pattern them.
- Can make formation of films and structures much easier.
- Is more economical than top-down in that it does not waste material to etching.

Bottom-Up Approach

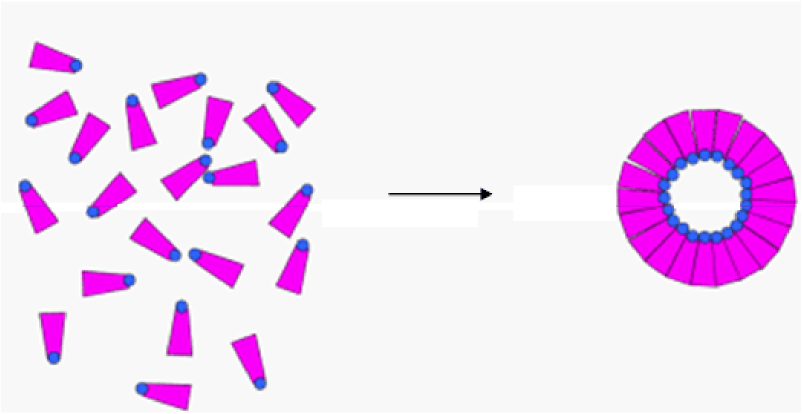


- The opposite of the top-down approach.
- The bottom-up approach selectively adds atoms to create structures.

http://idol.union.edu/~malekis/ESC24/KoskywebModules/sa_topd.htm

The Ideas Behind the Bottom-up Approach

- Nature uses the bottom up approach.
  - Cells
  - Crystals
  - Humans
- Chemistry and biology can help to assemble and control growth.



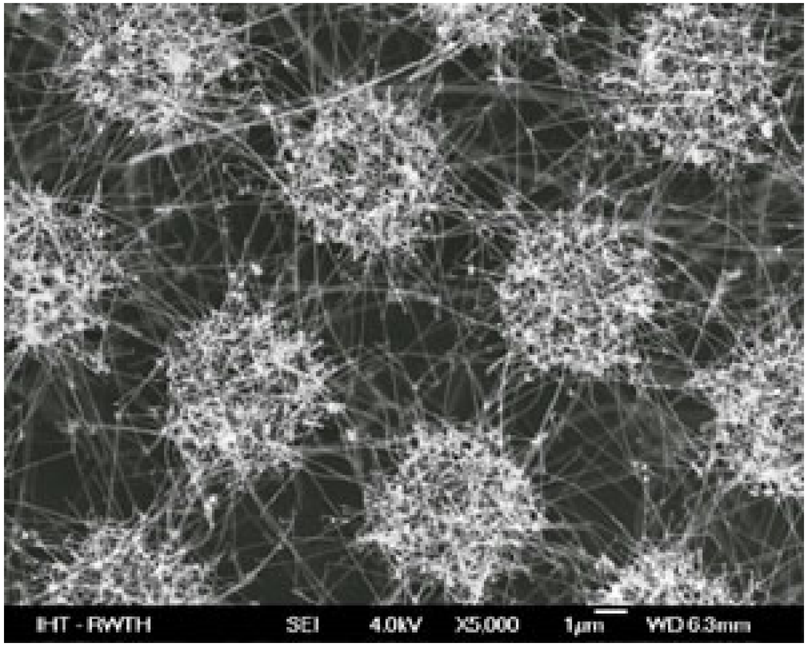
http://www.csacs.mcgill.ca/selfassembly.htm

Self Assembly

- The principle behind bottom-up processing.
- Self assembly is the coordinated action of independent entities to produce larger, ordered structures or achieve a desired shape.
- Found in nature.
- Start on the atomic scale.

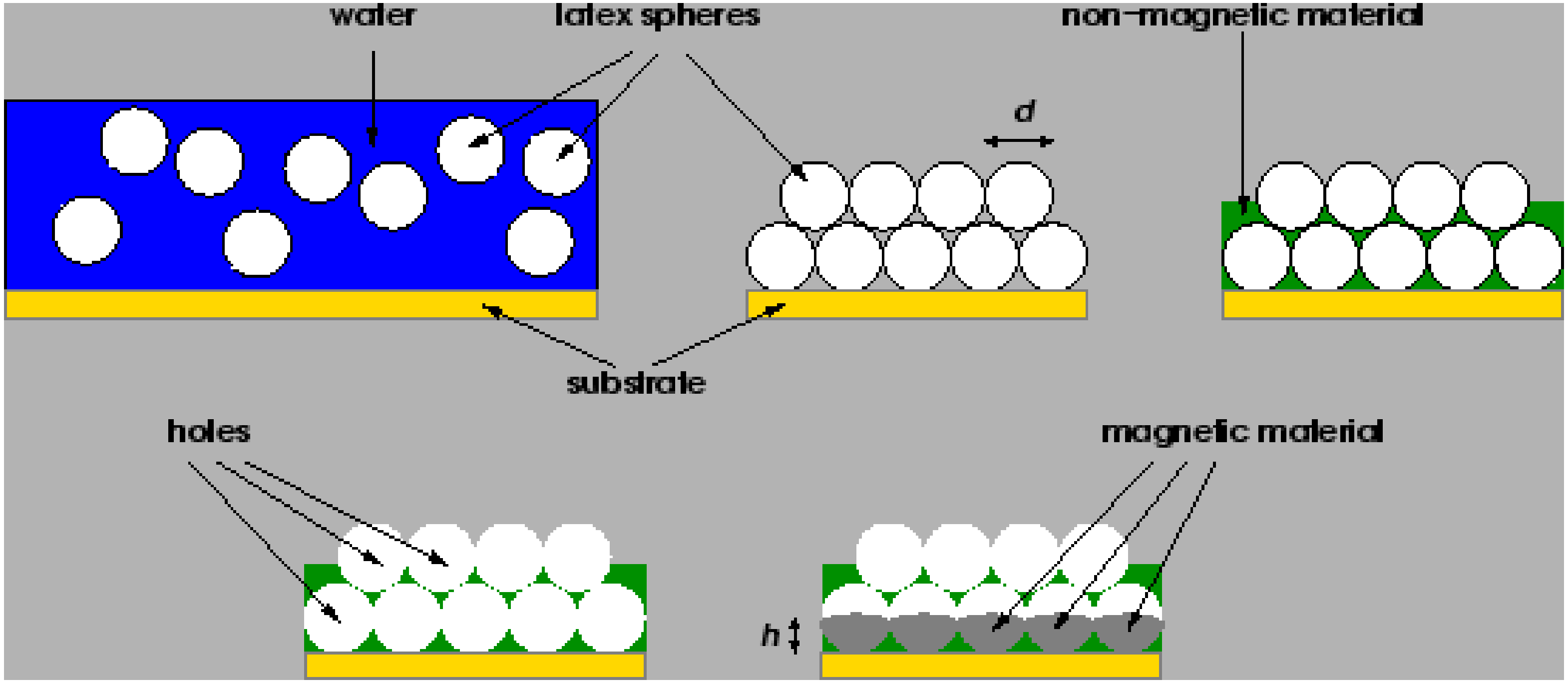
Applications of Bottom-Up Processing

- Self-organizing deposition of silicon nanodots.
- Formation of Nanowires.
- Nanotube transistor.
- Self-assembled monolayers.
- Carbon nanotube interconnects.



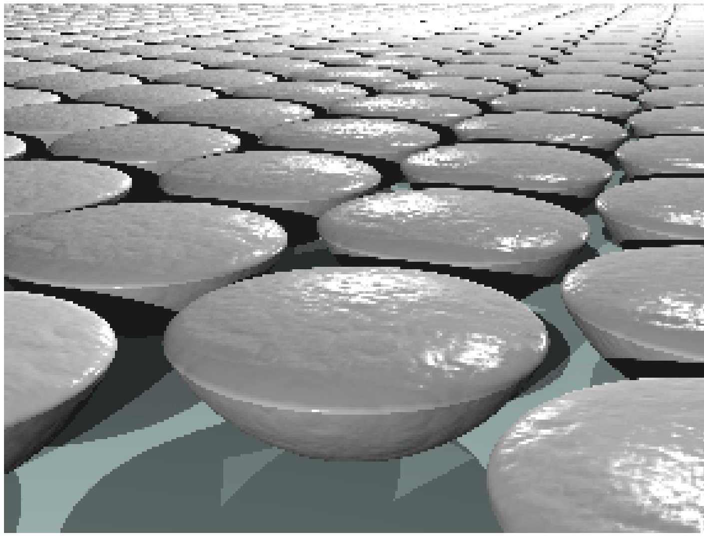
http://web.ics.purdue.edu/~mmaschma/bias_image_gallery1.htm

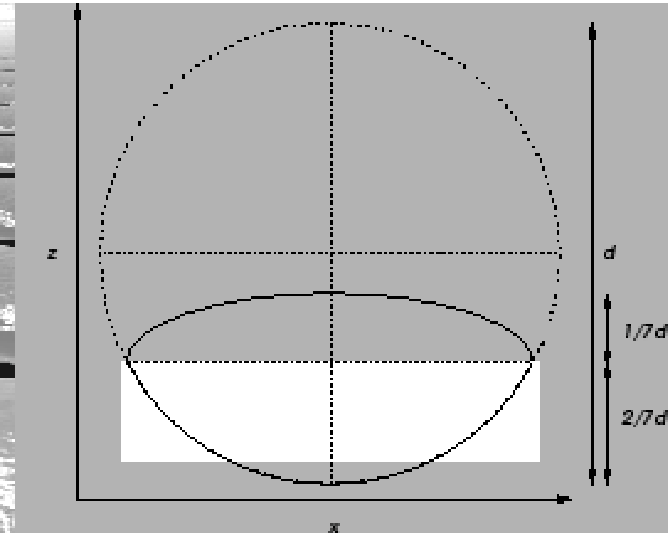
Making of Nanodots



The **double-template self-assembly technique**. First, an aqueous suspension of latex spheres (top left) of diameter **d** is poured onto a substrate. As the water evaporates, the latex spheres are attracted to each other (top centre), forming a regular close-packed structure. This template can be filled with a non-magnetic material (top right) and the latex spheres etched away (bottom left). The resulting gaps can be filled with a magnetic material to a varying height **h** (bottom right) to form arrays of connected or disconnected part-spherical nanodots.

Double-template self-assembly technique

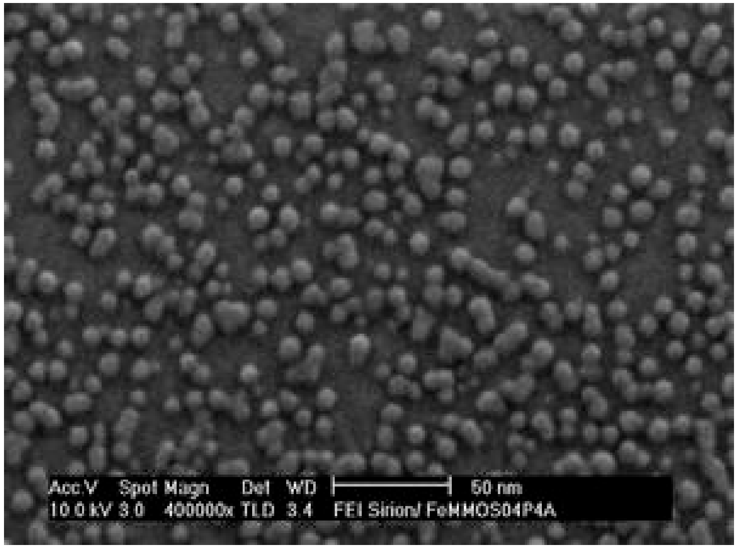




Using these templates, it is possible to create magnetic structures from sizes of 50nm to 1000nm by filling the spaces between the close-packed spheres with some material through electrochemical deposition.
By etching away the polystyrene spheres, another template is formed. This can then be filled with magnetic material, and by varying the fill amount of the resulting spherical holes, connected or disconnected arrays of dots can be formed. This is known as the **double-template self-assembly method**.

Self-organizing Deposition of Silicon Nanodots.

High-density information storage



http://www.iht.rwth-aachen.de/en/Forschung/nano/
bottomup/deposition.php

- Silicon nanodots are deposited onto silicon dioxide with no need for lithographic patterning.
- The nanodots can be thought of tiny magnets which can switch polarity to represent a binary digit.

Hard drives typically magnetize areas 200-250 nm long to store individual bits, while nanodots can be 50 nm in diameter or smaller

Recent Developments

Silicon quantum dots (SiQDs) are semiconductor Si nanoparticles ranging from 1 to 10 nm

Potential as optoelectronic devices and fluorescent bio-marking agents due to their ability to fluoresce blue and red light.

The methods for producing nanosized silicon particles include

1. Laser ablation and non-thermal plasma synthesis

2. Electrochemical etching, reduction of silicon halides, thermal destruction of silicon-rich oxides, hydrothermal decomposition of different Si-contained organic precursors, oxidation of sodium silicide, processing porous silicon etc

Front. Chem., 07 April 2020
| https://doi.org/10.3389/fchem.2020.0019

Bottom-Up Approach

Developing a simple, efficient method to organize molecules and molecular clusters into precise, pre-determined structure

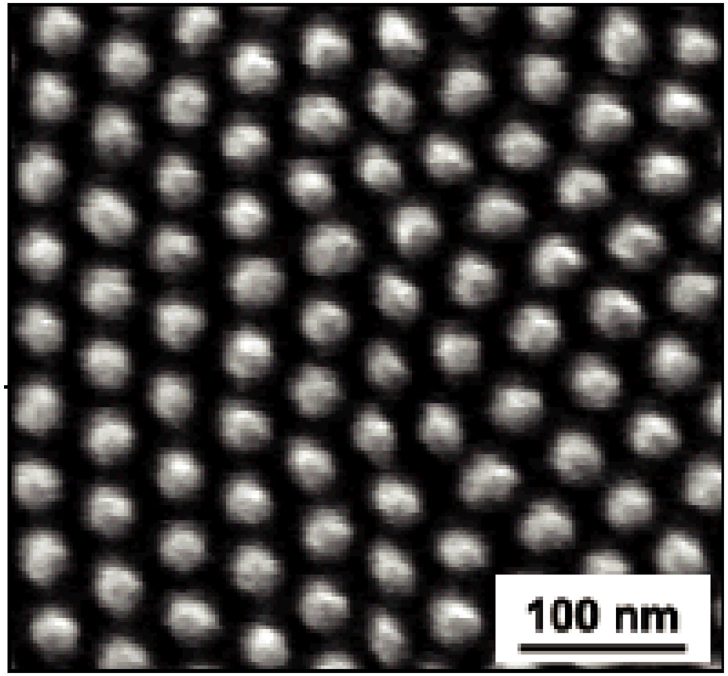
- Selectively adds atoms to create structures
- Nature - Cells, Crystals
- Chemistry and biology can help to assemble and control growth.

Making Nanodots

Polymer template for nanodot

Self-assembled polymer film

Grow layer of desired material



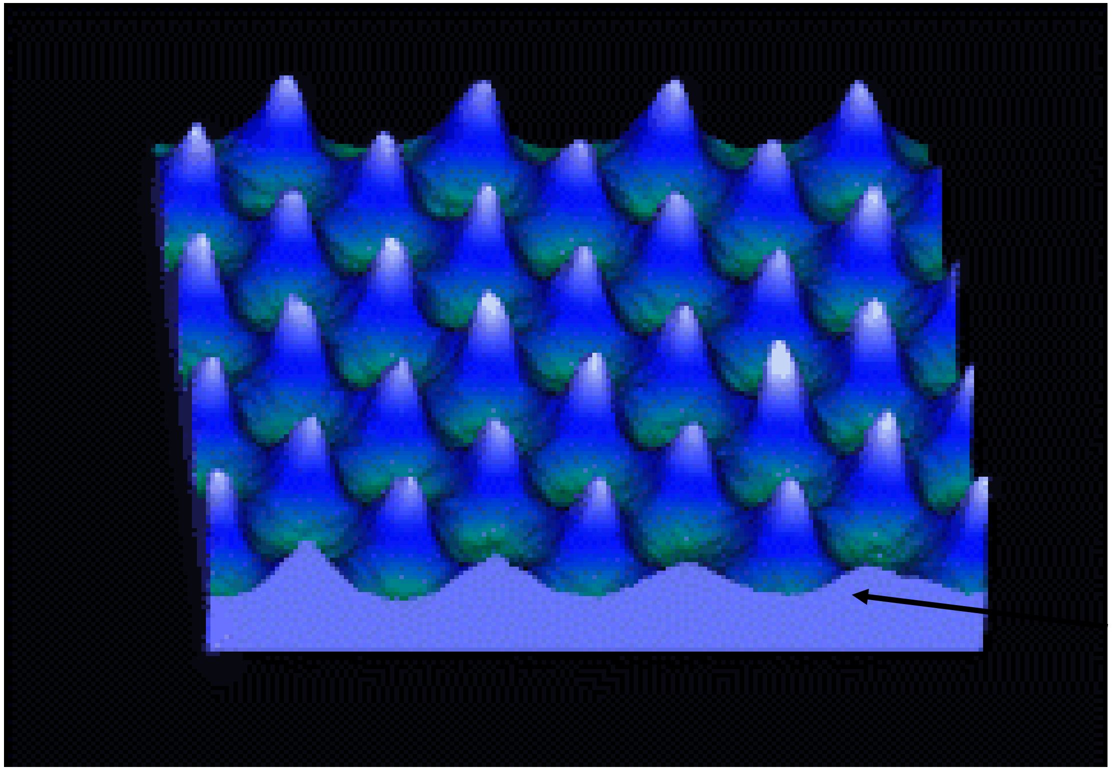
65 billion nanodots per square cm

http://news.bbc.co.uk/1/hi/sci/tech/33010241.stm

Self Assembled Nanodots

Each nanodot can hold one bit of information.

10 Trillion dots per square inch.



Future: Nanodot-based Smartphone Batteries

Energy storage - extremely fast recharge, *nanodots*, chemically synthesized bio-organic peptide molecules that, due to their small size, improve electrode capacitance and electrolyte performance. The end result is batteries that can be fully charged in seconds.

It acts like a **supercapacitor** (with very fast charging), and on the other is like a **lithium electrode** (with slow discharge).

The electrolyte is modified with nanodots in order to make the multifunction electrode more effective.

Summary

- Top-down processing – the prevalent choice - NOW
- Newer technologies for future products will require a bottom-up approach
- Combination of top-down and bottom-up processes to simplify fabrication?
- Self-assembly

Process and Plant Design

The process and plant design procedure begins with a product idea or product formula, tested in the laboratory with stirred beakers or standard calorimeters.

The chemical recipes and protocols are developed, which must be transferred into a technical process.

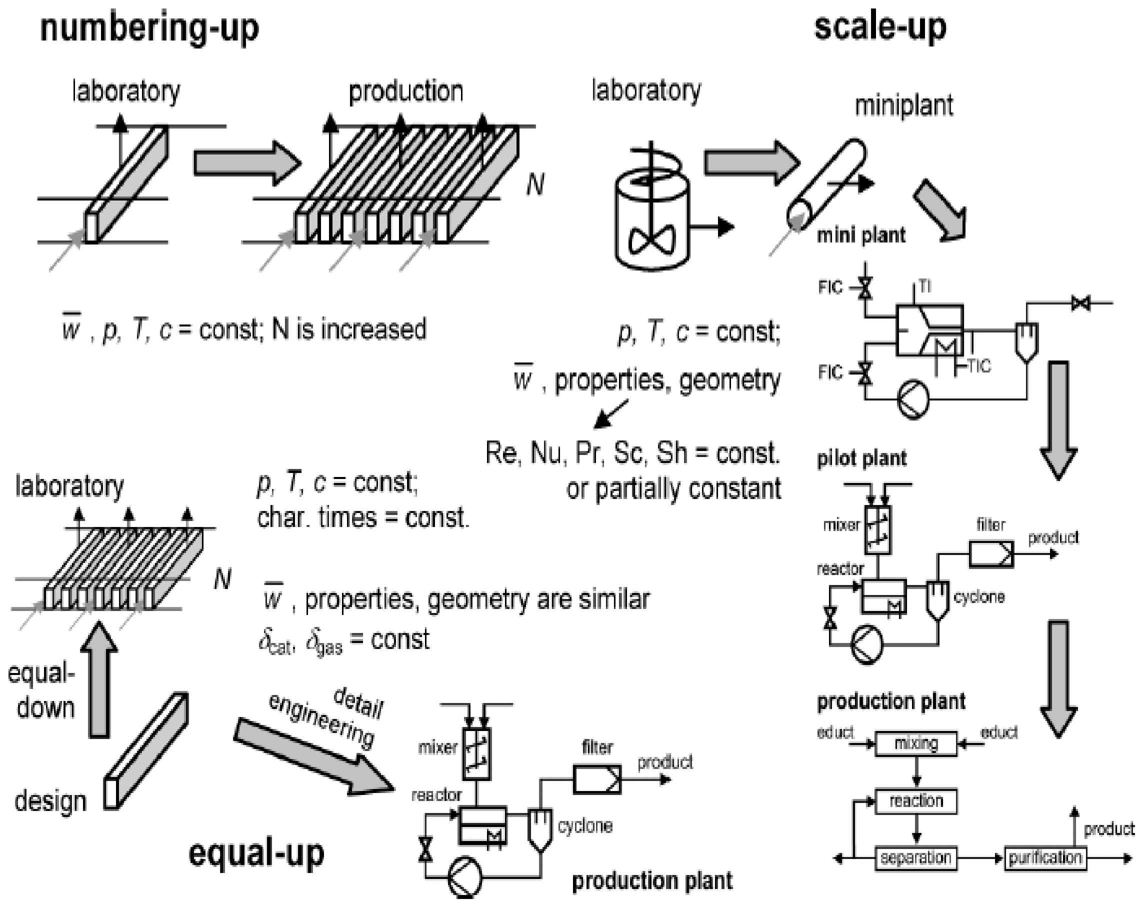
Conventional way,

Miniplant $\longrightarrow$ Pilot Plant $\longrightarrow$ Production facility

Right side of Figure

Scale-up, Numbering-up

In conventional process engineering, the scale-up process is quite elaborate, Starting with laboratory experiments, the gained data are transferred to mini plants with almost the same length scale, but a more accurate representation of continuous flow processing.

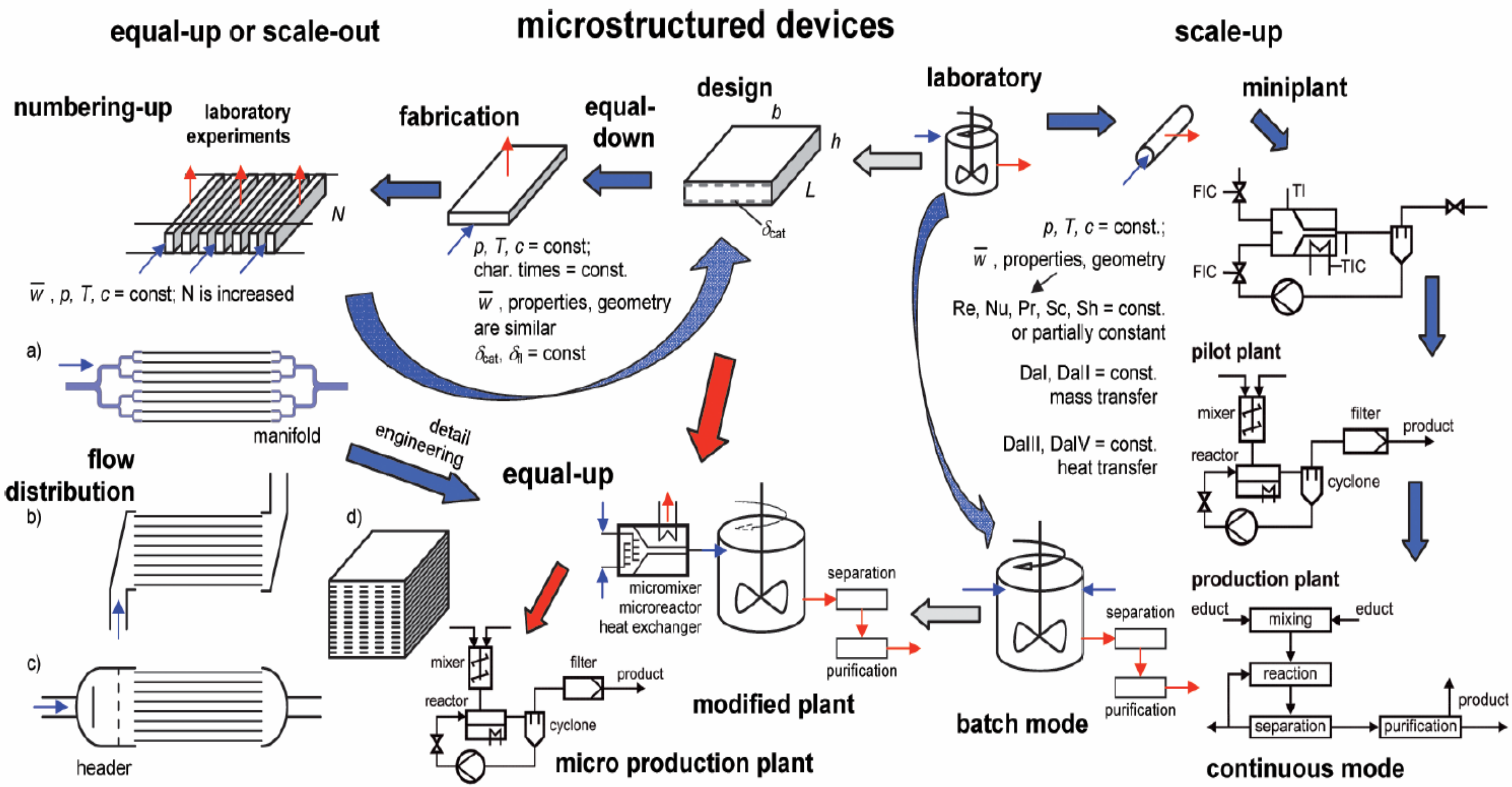


The pilot plant provides feedback on a semi-industrial scale for the correct design of the final production plant. Wherever possible the process conditions of temperature, pressure and concentrations are kept constant.

Channels are the basic element of microstructured equipment, often with rectangular cross section.

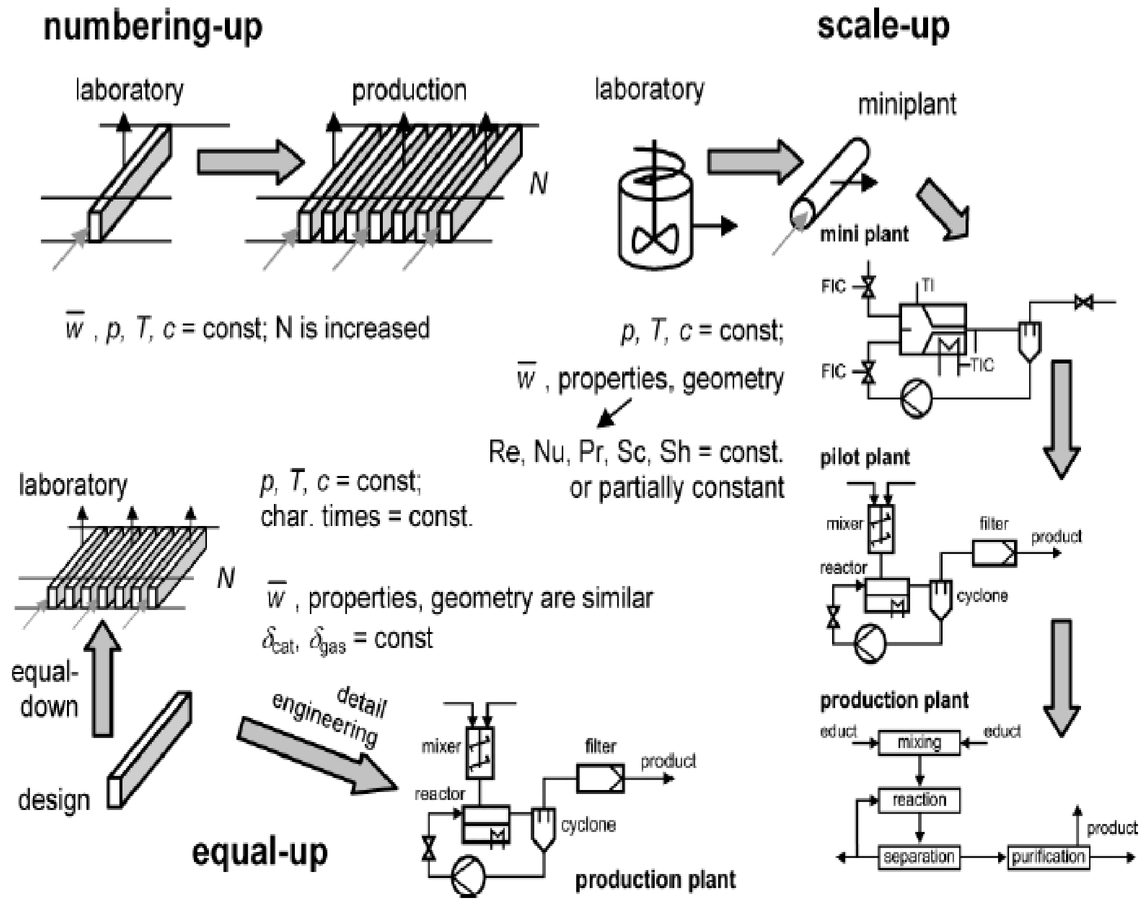
Depending on the process conditions, such as temperature, pressure, and fluid properties, the channel cross section, catalyst layer (if necessary), and minimum numbers are determined on the basis of available fabrication technology and device material.

This process is called **equal-down,** because the small channel dimensions are determined according to the necessary heat and mass transfer and relevant chemical kinetics.



Equal-up and scale-up procedures with microstructured devices

The geometry is represented along with suitable process parameters in dimensionless numbers like the Reynolds number Re or Sherwood number Sh, which are kept constant or at least partially constant for the process transfer.



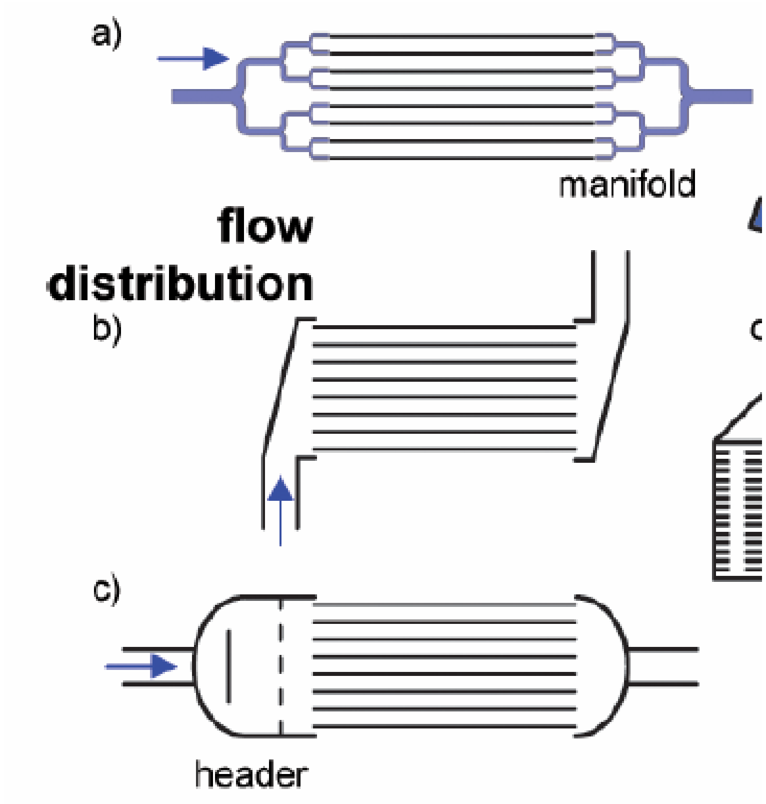
The **numbering-up** procedure increases, in the simplest approach, just the number of channels, to enlarge the capacity. The flow distribution and correct integration must be considered and are the major critical points for a successful implementation. With more channels in a microstructured device, well designed manifolds are extremely important for performance.

A laboratory device is fabricated and tested with the chemical system to yield experimental data. This data is compared with design assumptions and preliminary simulation results.

In case of successful experimental tests, the next design step is to layout a device or a number of devices handling the desired product capacity - **internal numbering-up** of these elements increases the entire flow rate.

The **flow distribution** and correct integration is the most critical point for successful implementation.

Depending on the size of the entire device, various fluidic manifolds or flow headers can be applied.



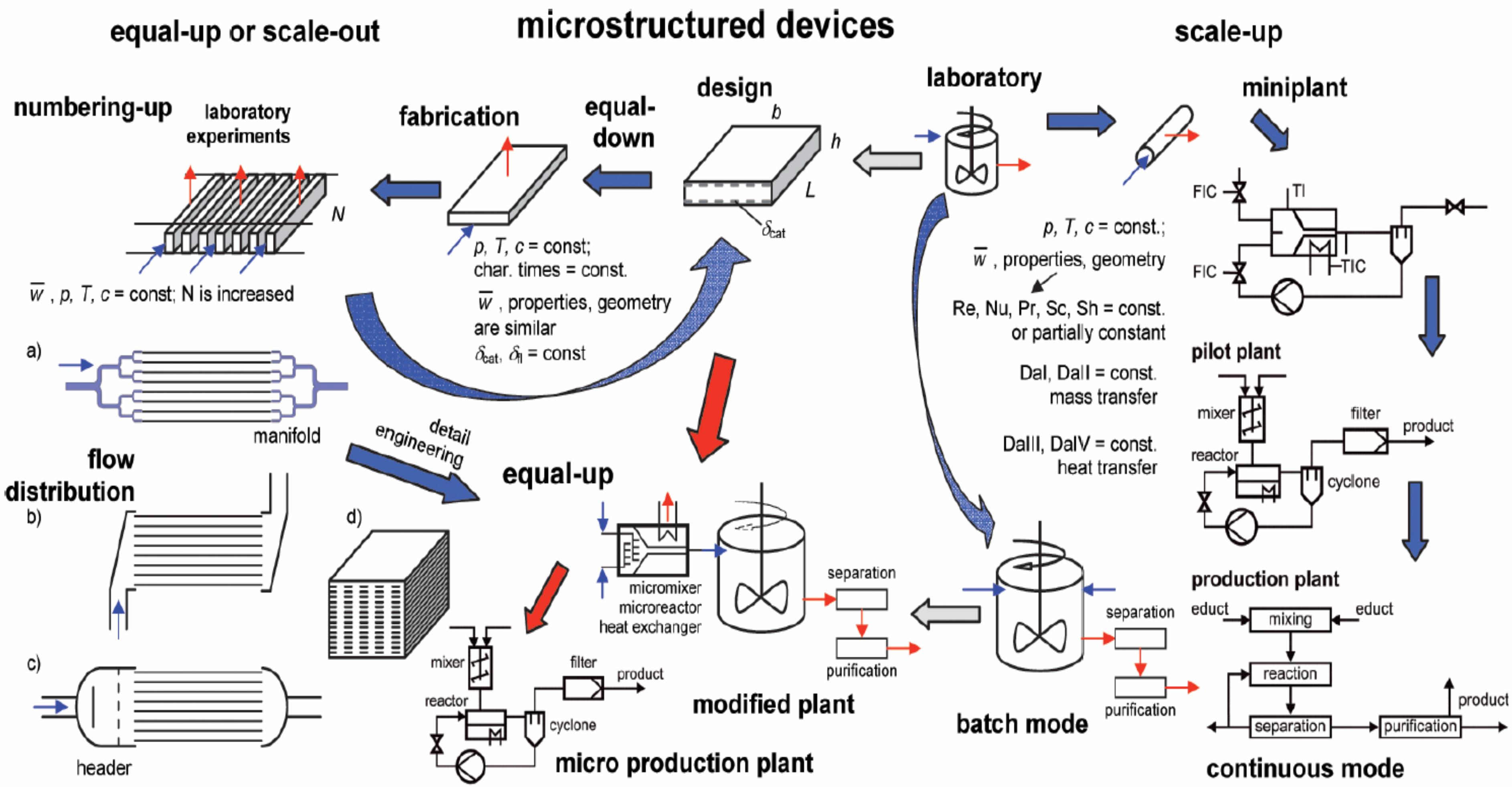
The velocity of the inlet flow is directed to the side walls by a central plate. With this arrangement, all channels are facing the same fluid velocity and are supplied with uniform flow rate.

The appropriate flow manifold depends on the number of channels as well as the shape of the entire device.

Microstructured devices for high flow rates often consist of a stack of microstructured plates.

Experimental experience and proper integration of microstructured elements in a conventional apparatus are essential in order to design and fabricate this plate stack.

The **equal-up process** starts from the process or product to be realized, and the main effects and parameters are identified for miniaturization.



Equal-up and scale-up procedures with microstructured devices

These key parameters to the production design are with respect to key geometries, fluid dynamics, mixing, reaction kinetics, and heat management.

The experimental results indicate, which dimensions cause the benefits of the small length scale (e.g. the boundary layer δ_{fl}).

Other design parameters from fabrication have to be transferred to the production device, such as shape and structure of the active surface , e.g. the catalyst layer thickness δcat.