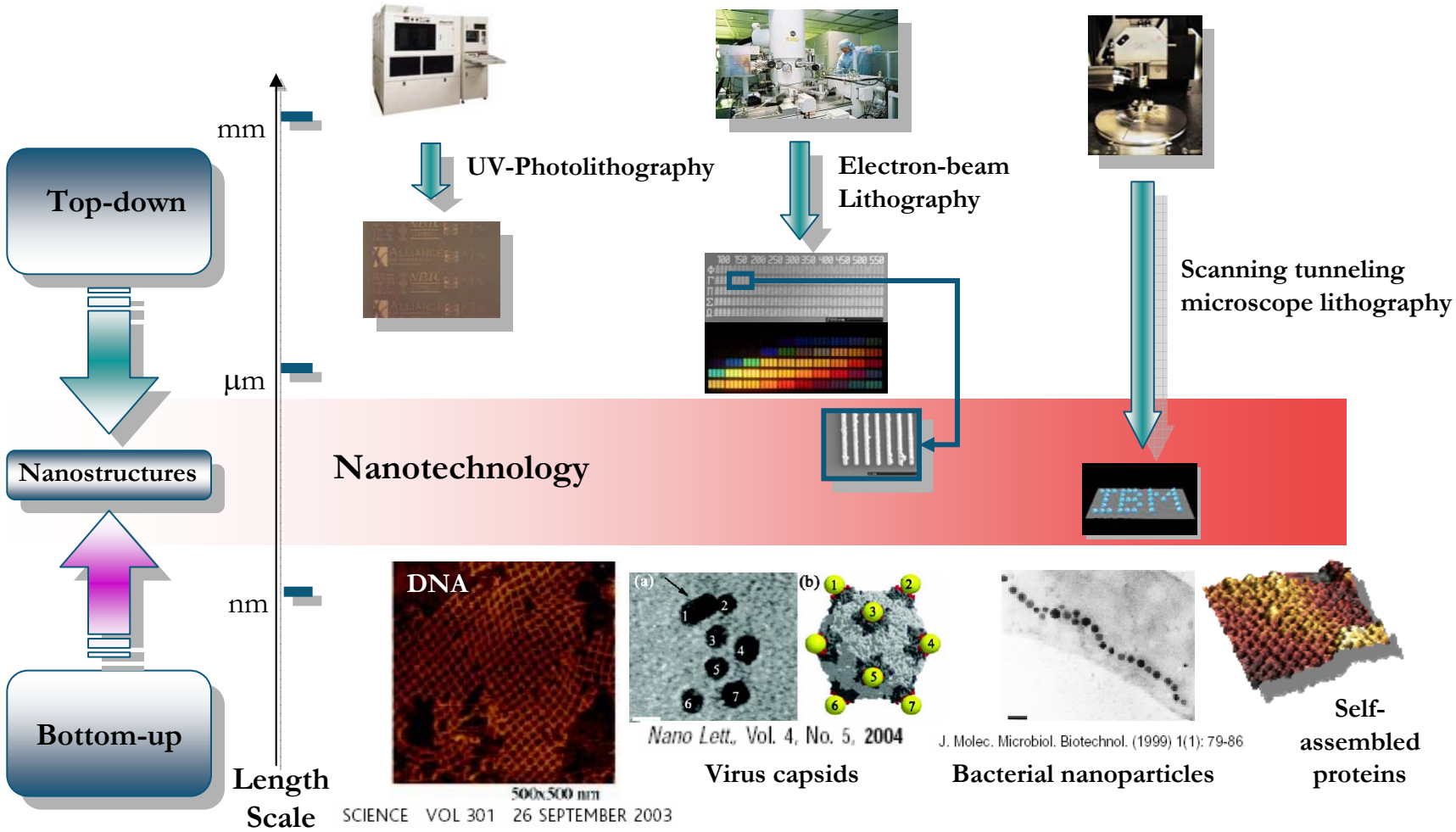
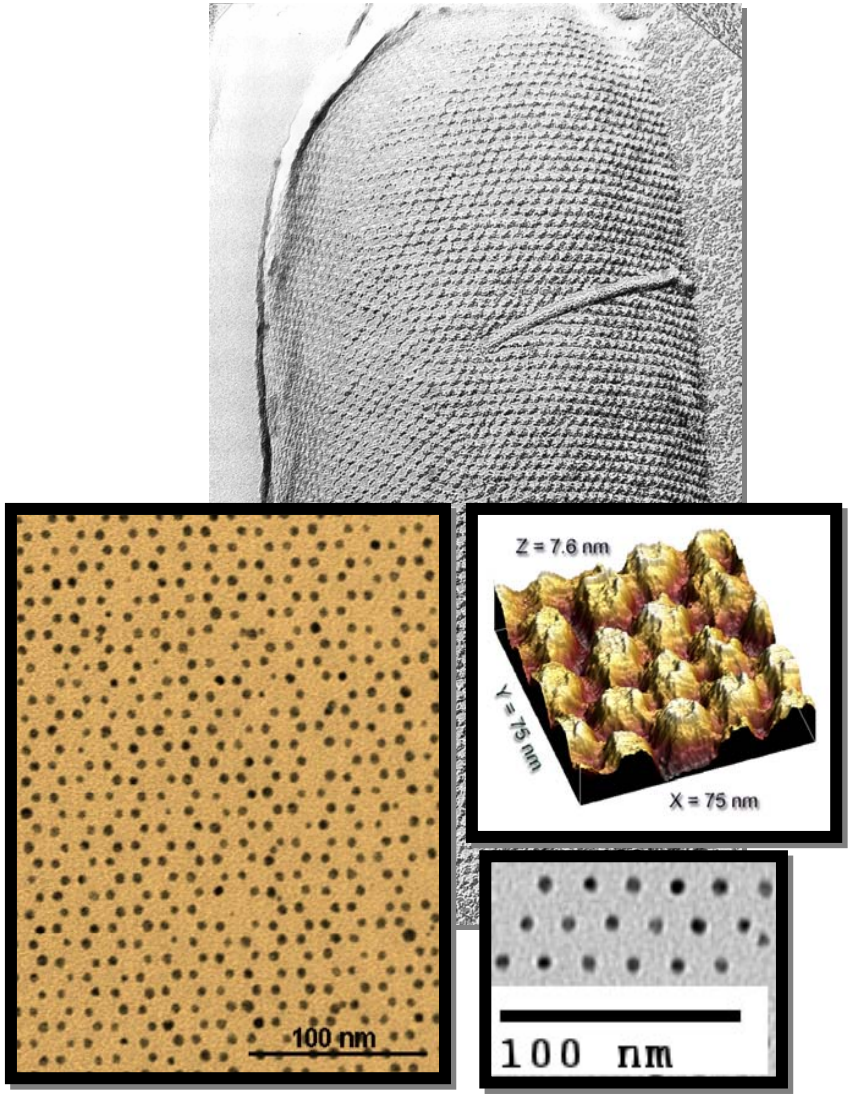
Conventional Micro/Nanofabrication Technology in Semiconductor Industry



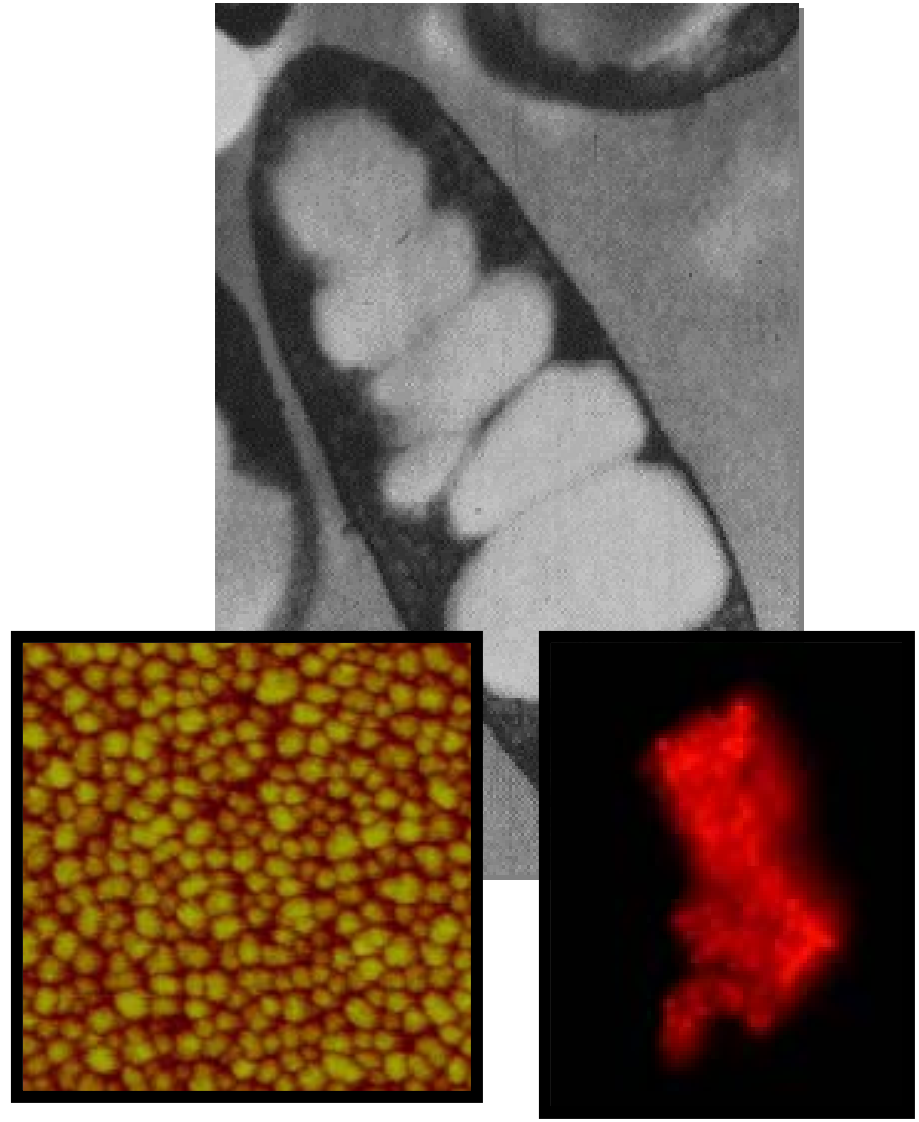
Creating small structures using "biological systems"

Bionanofabrication – a process that takes advantage of structural specificity and/or catalytic activity of the biological systems to create various types of micro/nanostructures

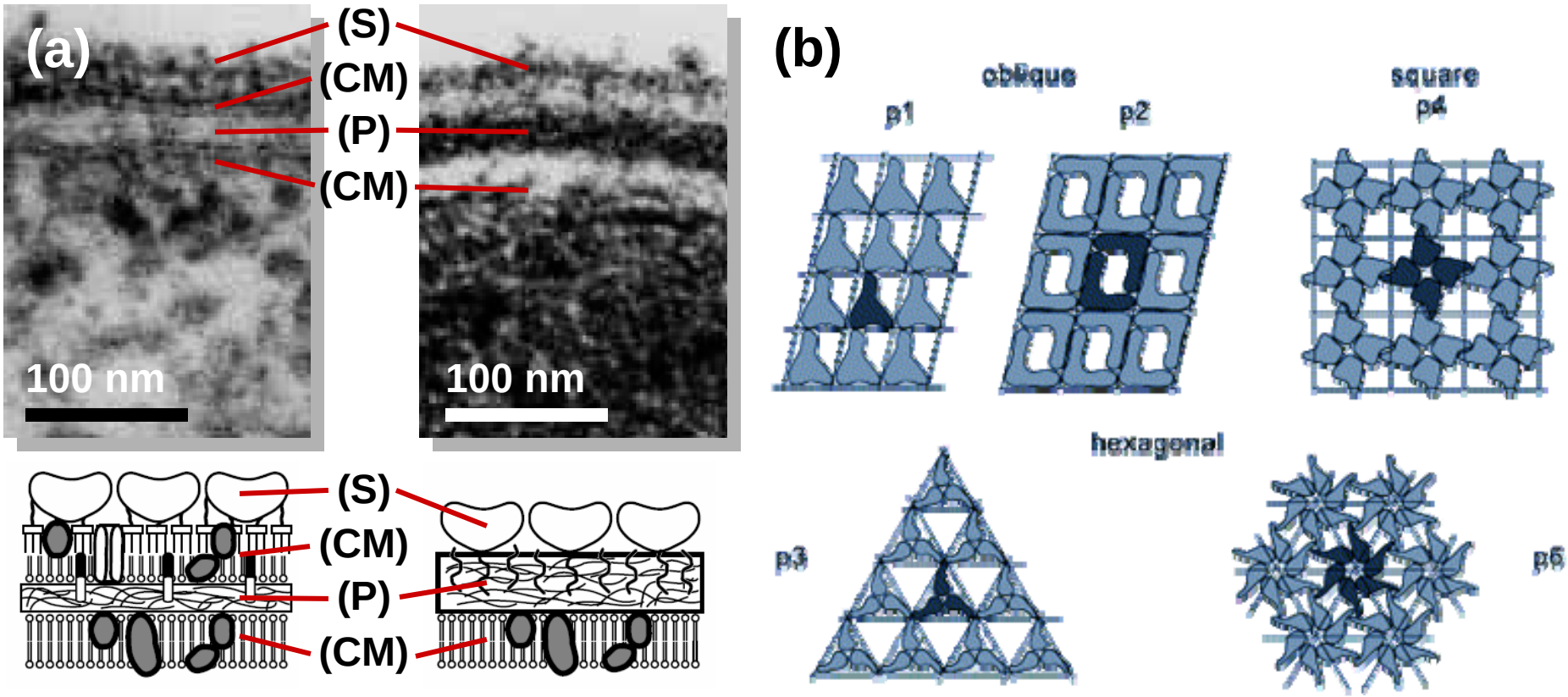
Bacterial S-layer Proteins



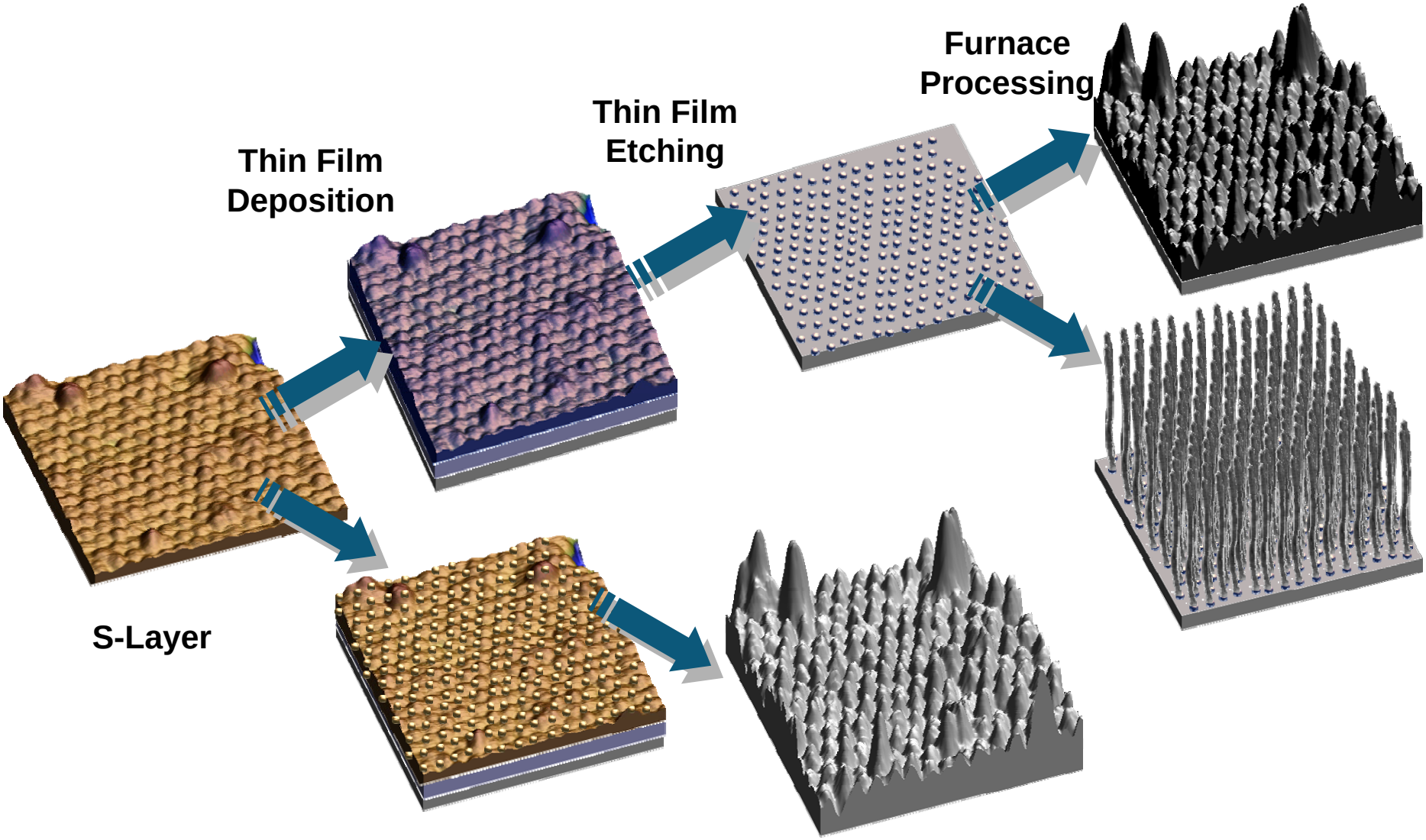
Bacterial Polyester



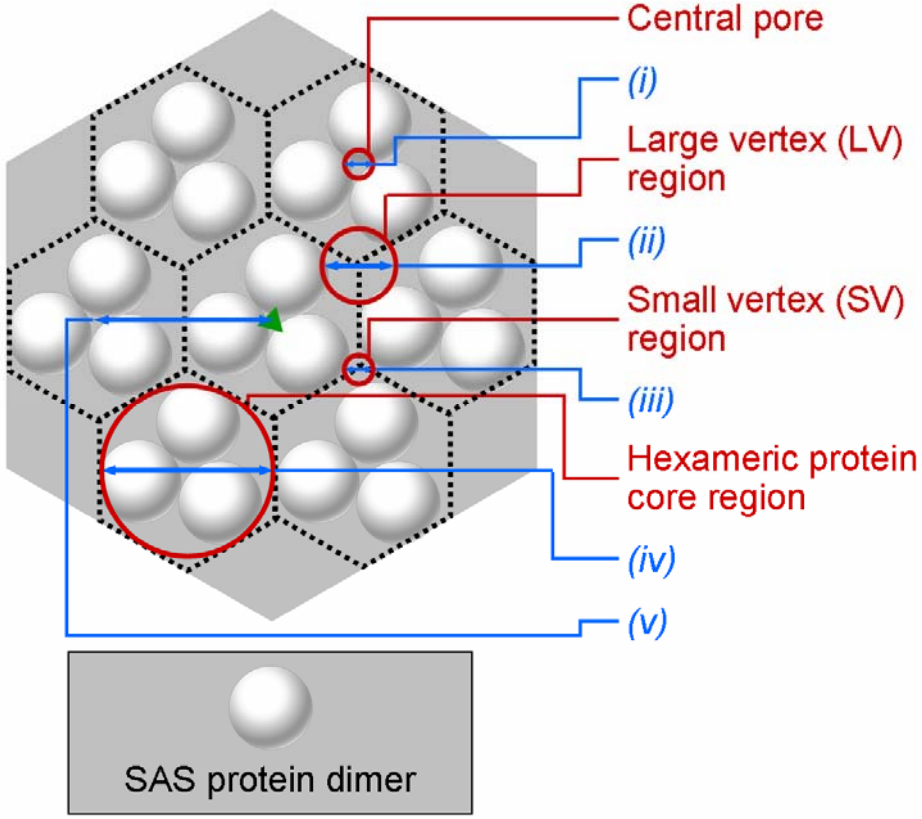
Surface Layer (S-Layer) Proteins

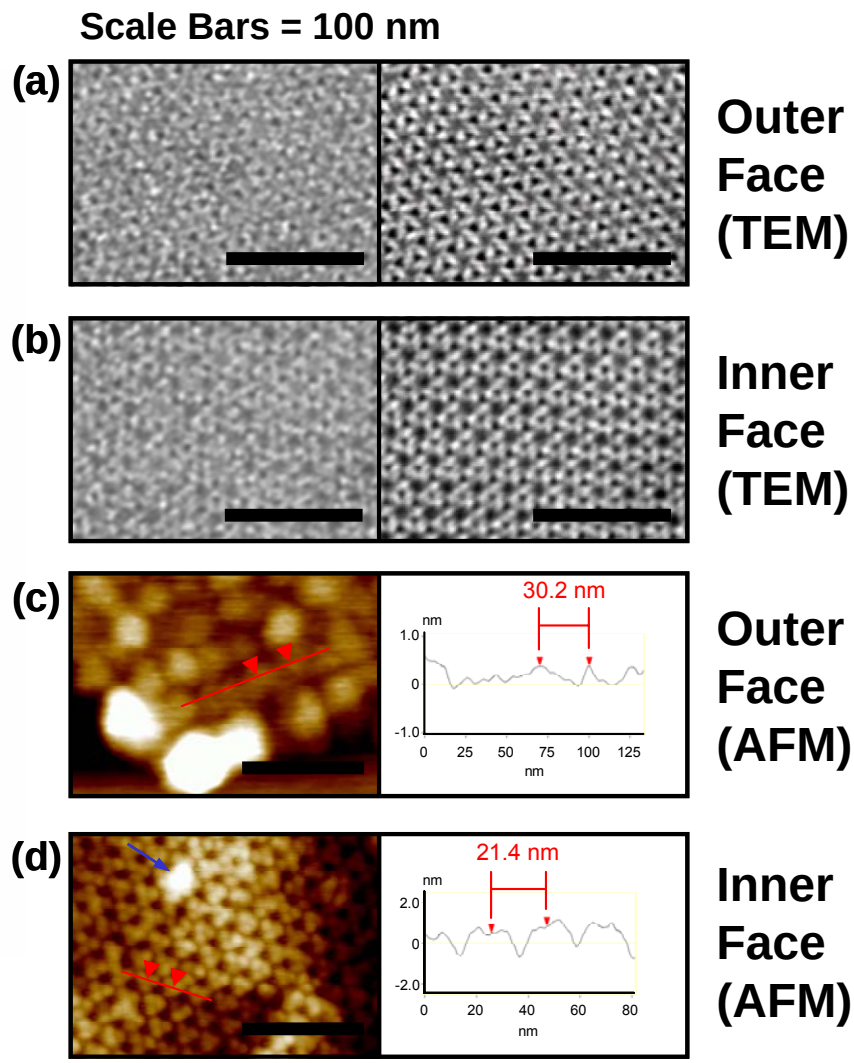


(a) Comparison of Gram-negative (left) and Gram-positive (right) cell wall structures. **(S)**, S-layer; **(CM)**, cell membrane; **(P)**, peptidoglycan. **(b)** Types of S-layer morphologies


Thin Film
Deposition
Thin Film
Etching
Furnace
Processing
S-Layer

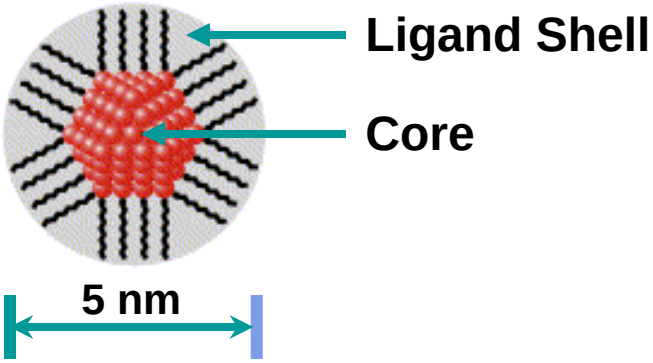
Morphology of the *Sulfolobus acidocaldarius* S-layer (SAS)



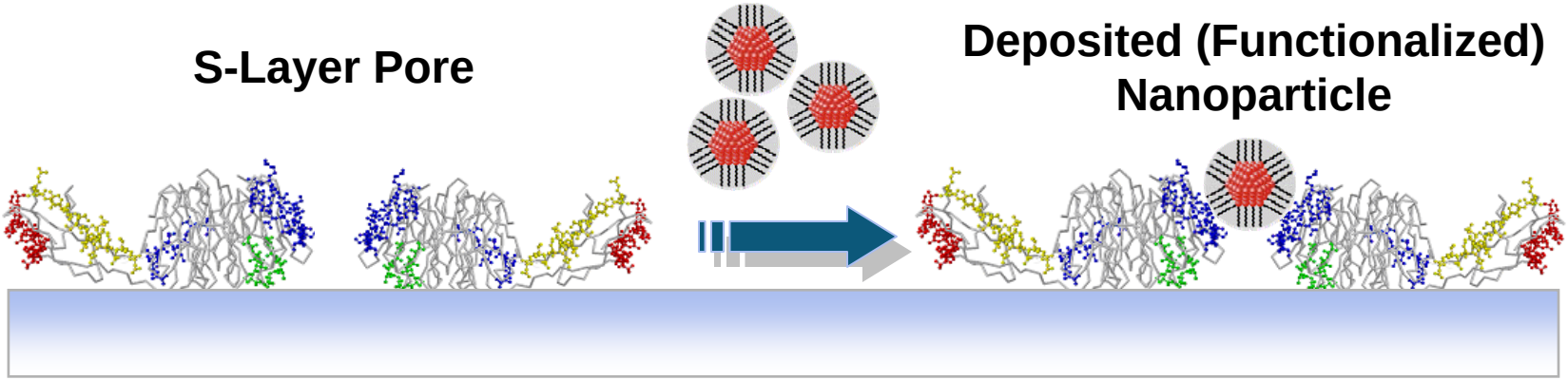


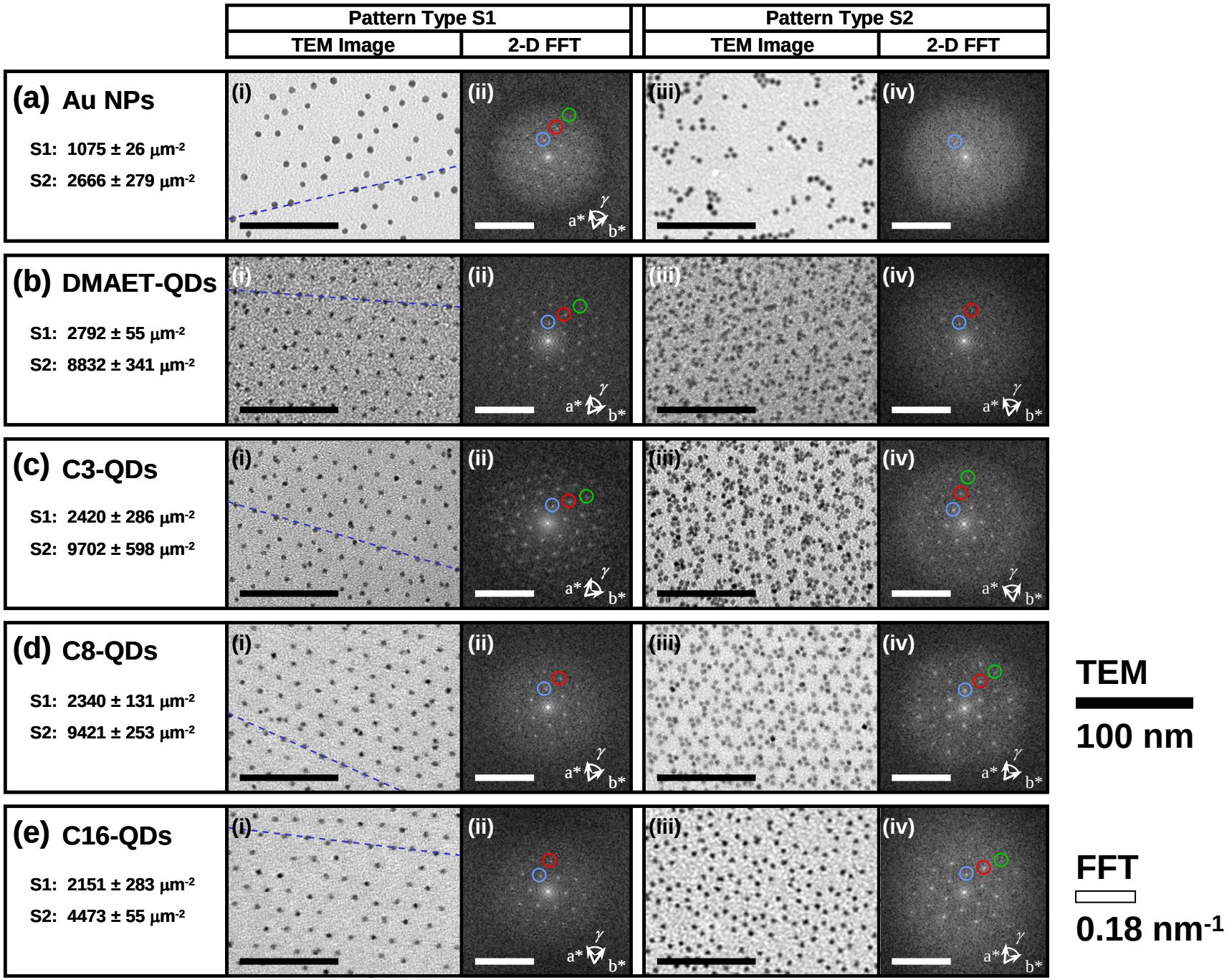
Nanoparticle Patterning On S-Layers

We investigated the deposition of metal /semiconductor nanoclusters into the pore/vertex regions of HPI and SAS by using different types of capping ligands



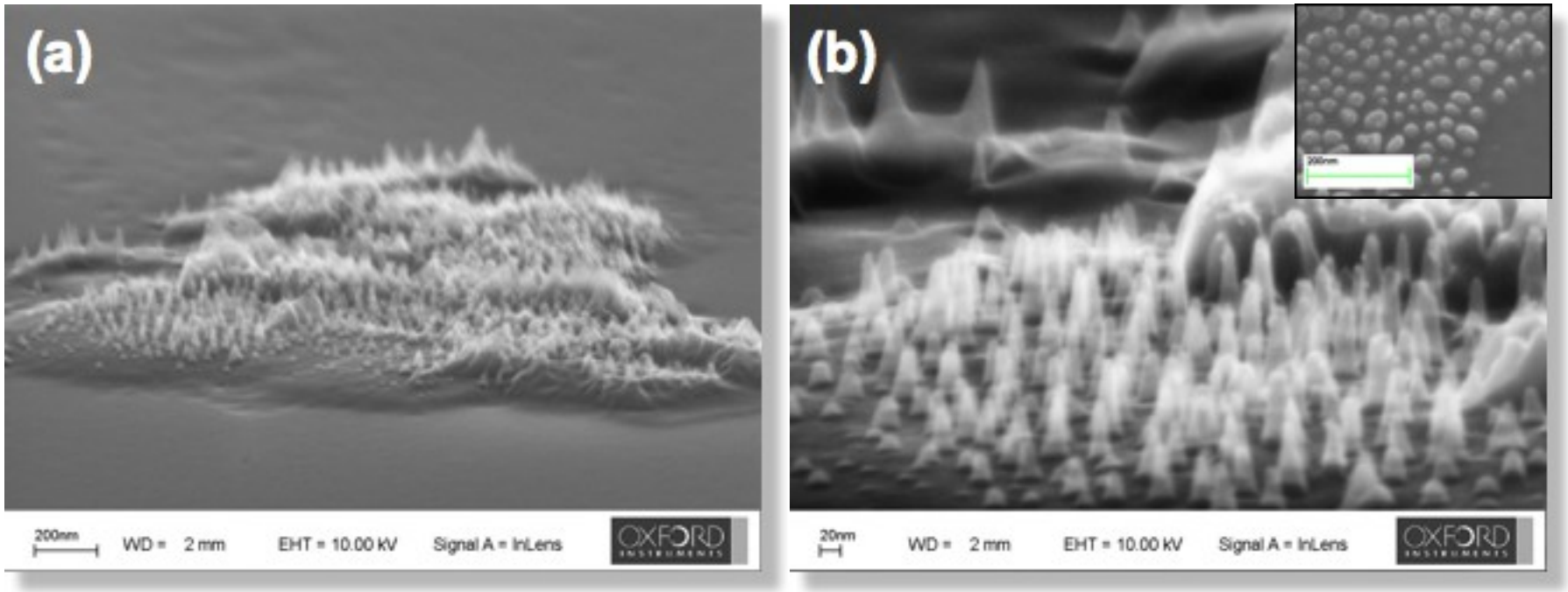
- Metal or semiconductor nanoparticles with charged surface-capping molecules are deposited at specific regions on the S-layer through electrostatic and/or other binding interactions.
- Permit better control over material quality and size uniformity (monodispersity)
- A wide range of different types of nanomaterials can potentially be arrayed




Pattern Type S1
Pattern Type S2
TEM Image
2-D FFT
TEM Image
2-D FFT
(a) Au NPs
S1: 1075 ± 26 μm-2
S2: 2666 ± 279 μm-2
(b) DMAET-QDs
S1: 2792 ± 55 μm-2
S2: 8832 ± 341 μm-2
(c) C3-QDs
S1: 2420 ± 286 μm-2
S2: 9702 ± 598 μm-2
(d) C8-QDs
S1: 2340 ± 131 μm-2
S2: 9421 ± 253 μm-2
(e) C16-QDs
S1: 2151 ± 283 μm-2
S2: 4473 ± 55 μm-2
(i)
(ii)
(iii)
(iv)
a*
b*
γ
TEM
100 nm
FFT
0.18 nm-1

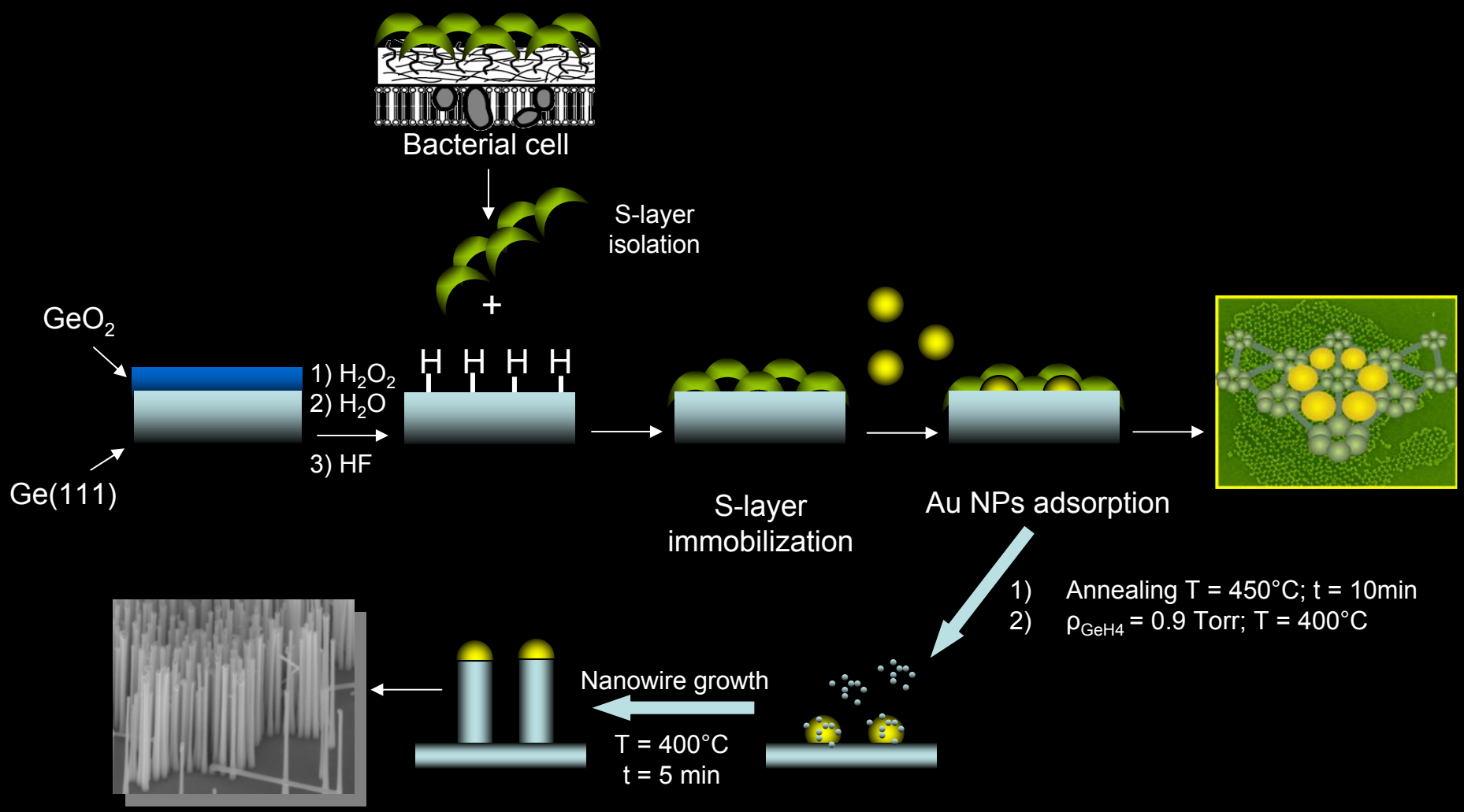
Si Nanopillars Using Biotemplated Au Nanoparticles as Etch Masks for $SiCl_4$ ICP

- **1.5 mTorr, 20 °C, 60 sec etch**

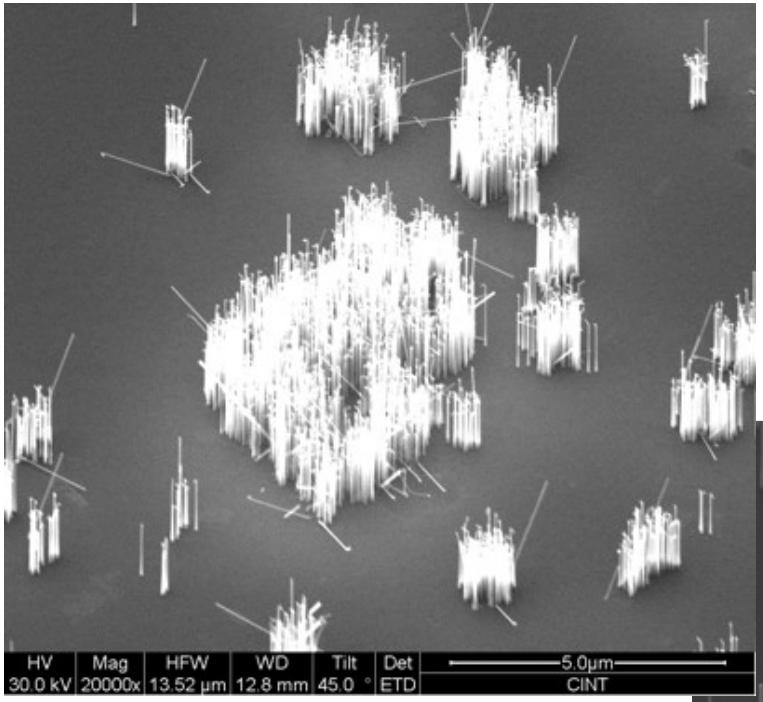


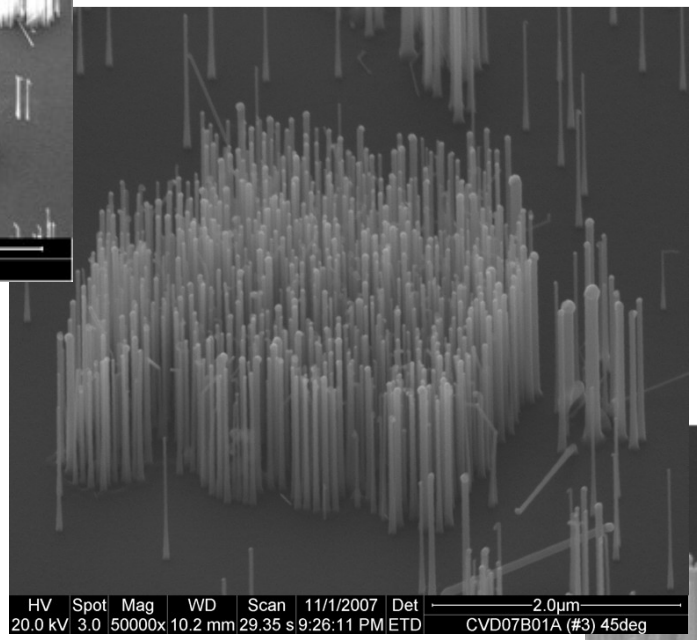
Silicon nanopillars after $SiCl_4$ ICP process. (a) Low-mag image. **(b)** Higher-mag image. SNPs are approximately 8-13 nm wide at the tip, 15-20 nm wide at half-height, 20-30 nm wide at the base and ~100-120 nm tall. SNPs are spaced ≥25 nm apart.

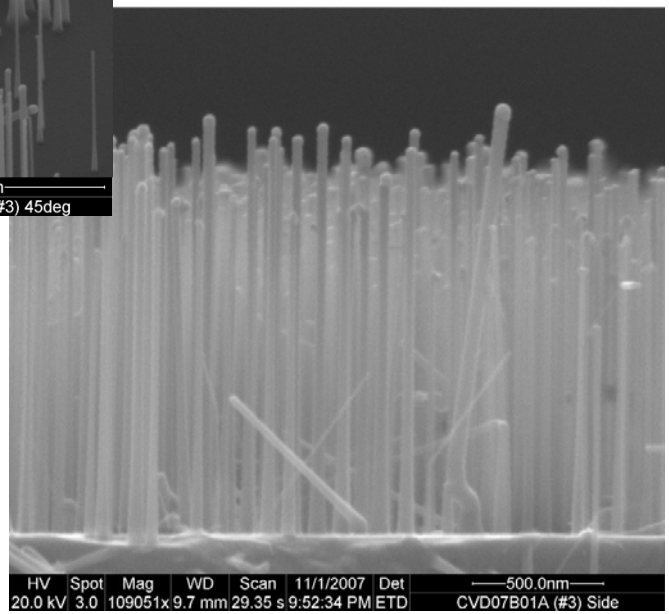
Nanowire growth



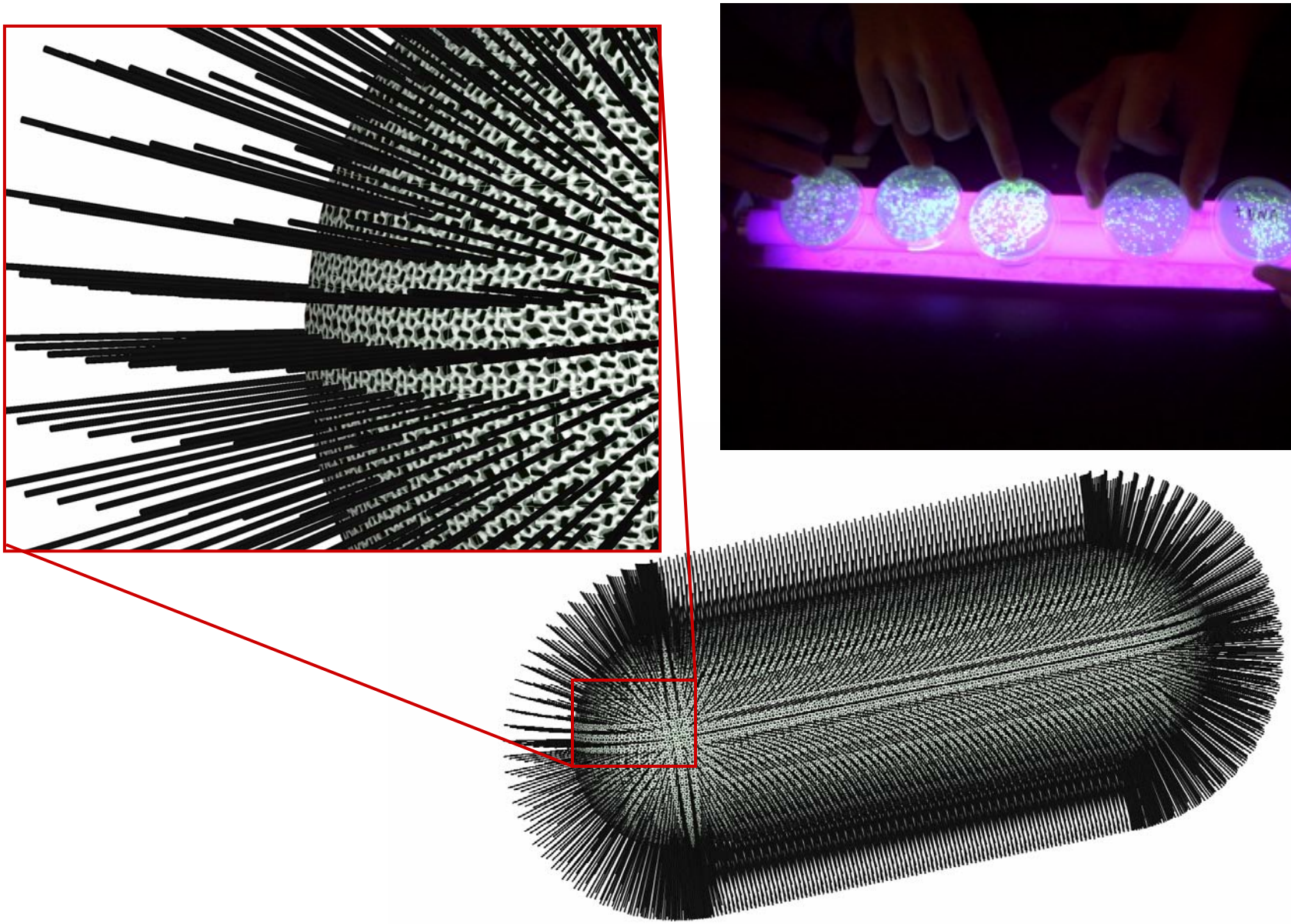
Ge nanowires on s-layers



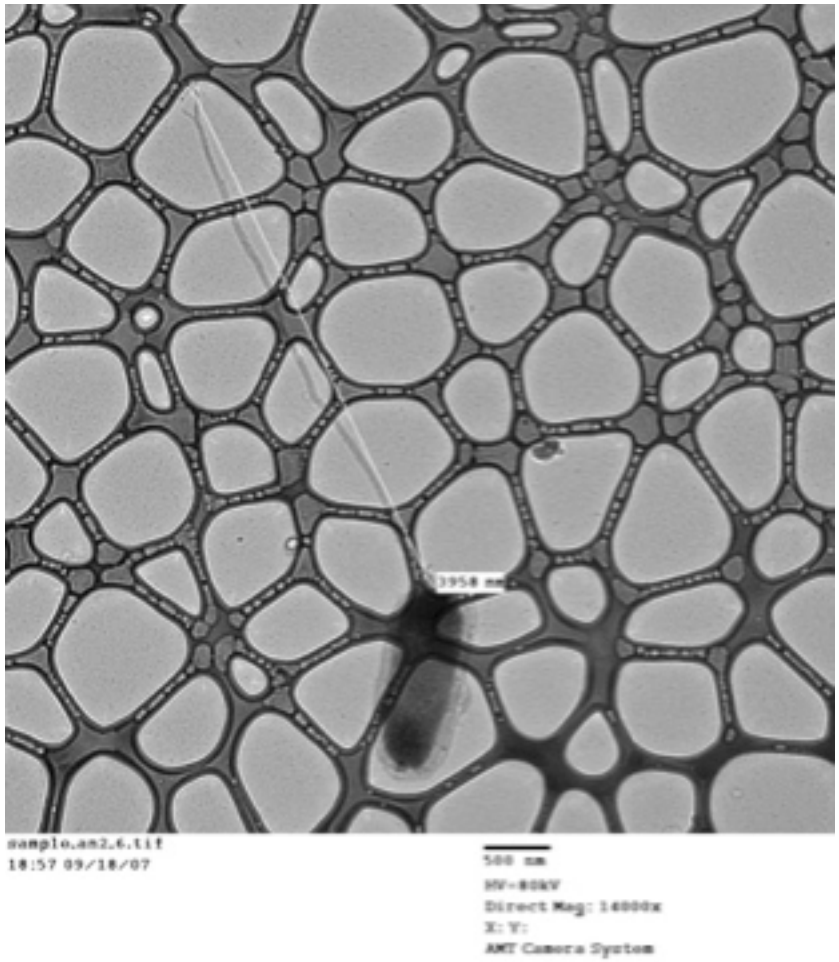


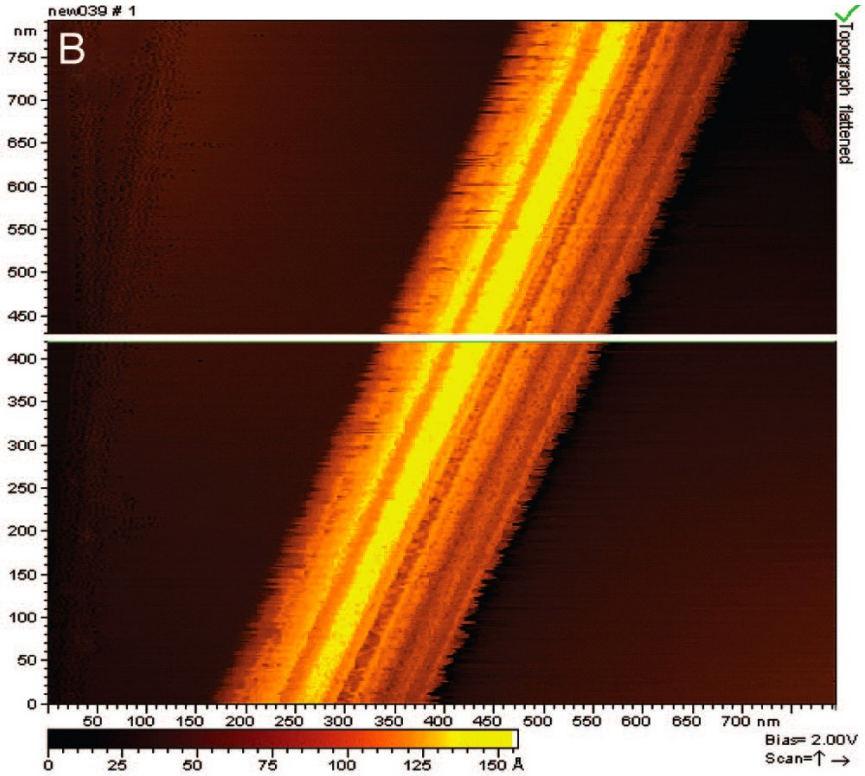


Nice tricks



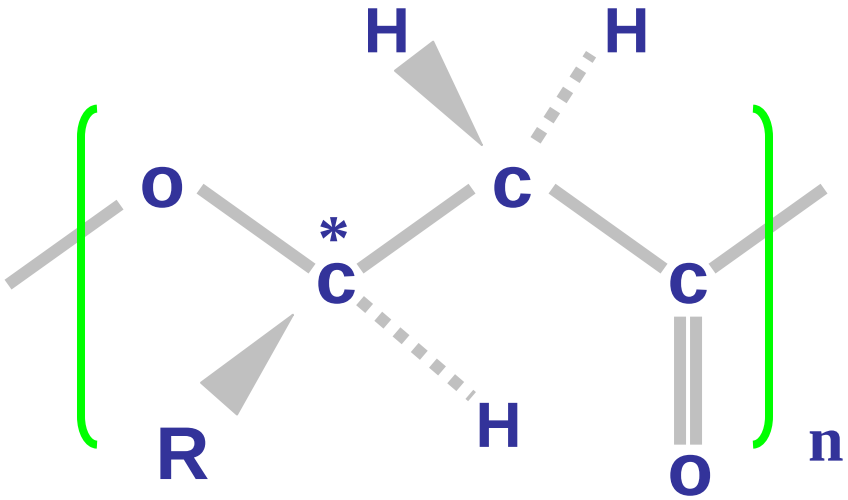
Bacteria…nanowired





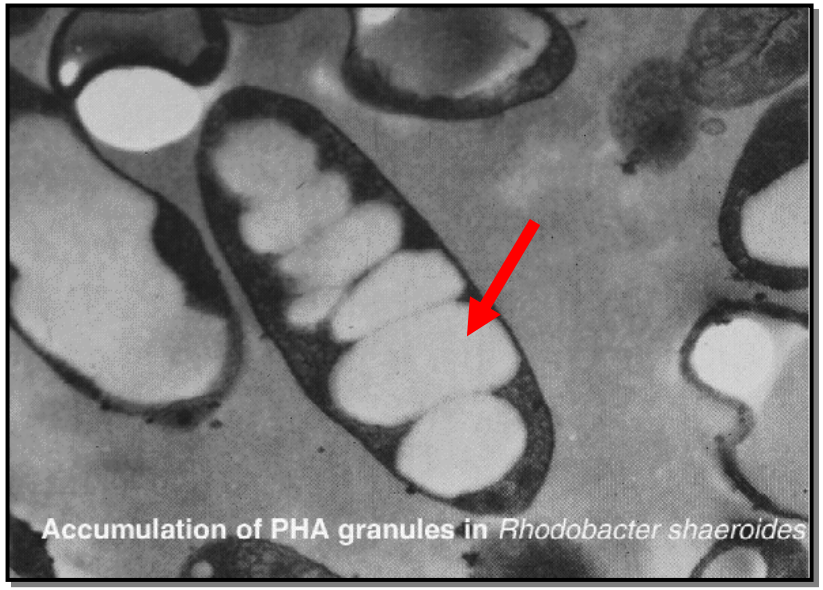
Intermission

Poly(3-hydroxyalkanoates) or PHAs

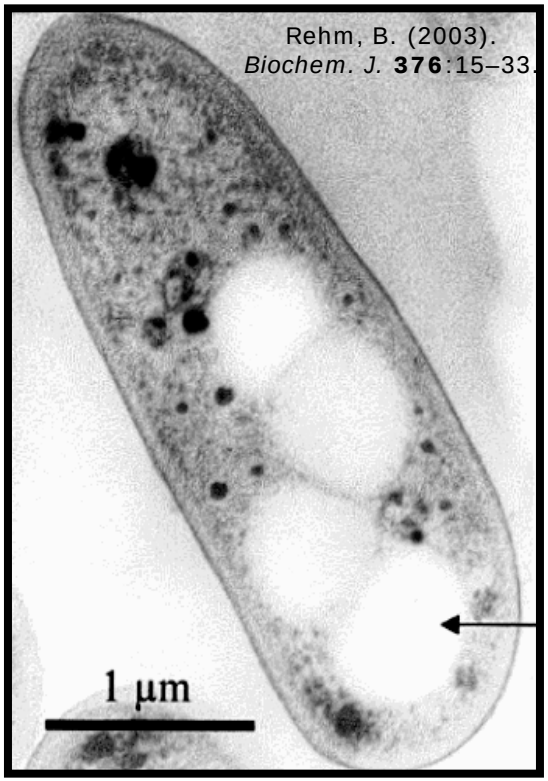


All monomers have one chiral center (*) in the *R* position

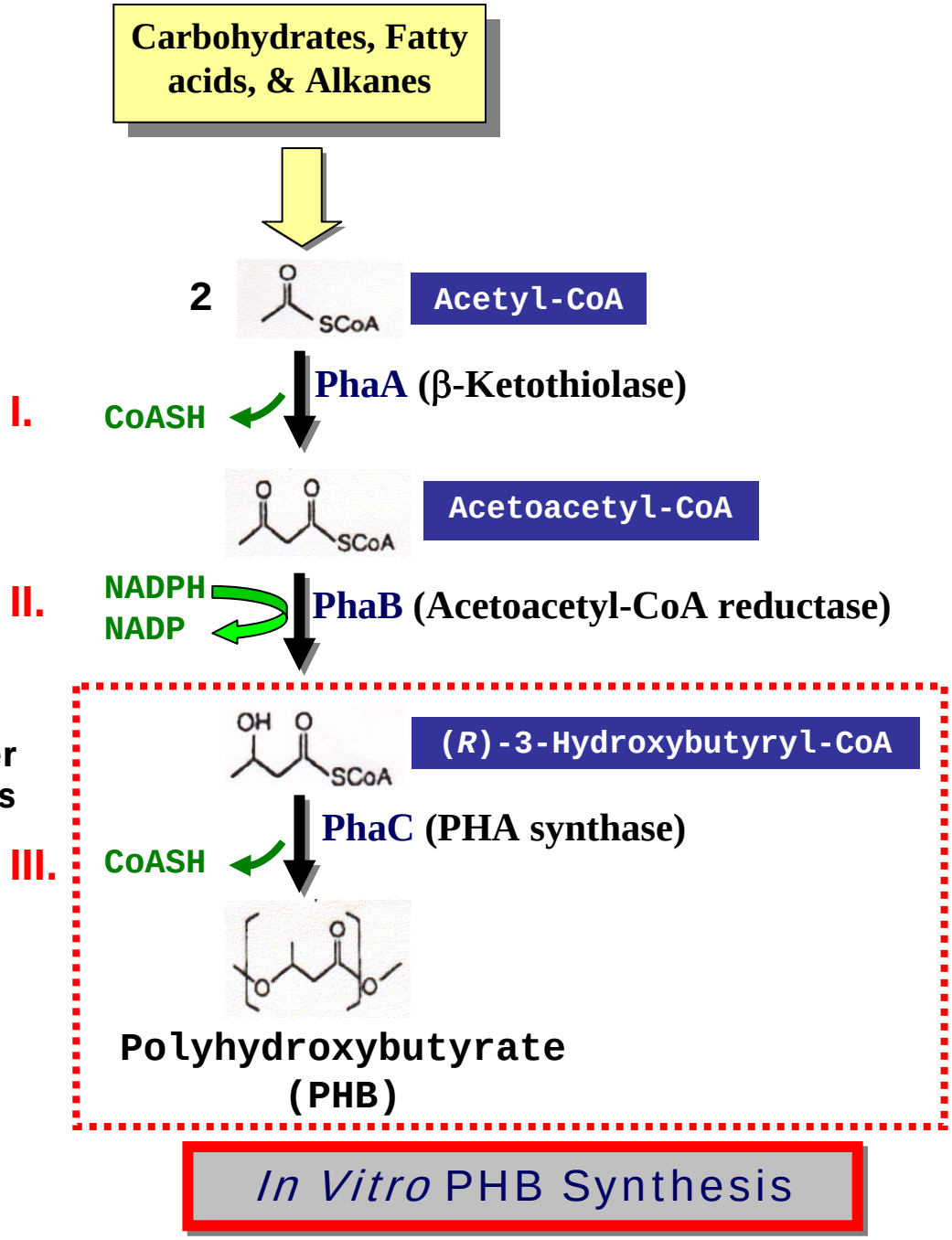
n = 100 to 30,000 repeating units



- **Aliphatic polyesters**
- **Intracellular carbon & energy storage compounds**
- **Non-crystalline inclusion bodies**
- **Biodegradable**
  - By enzymatic reaction
  - By chemical hydrolysis
- **Biocompatible**
- **Different side chain substitutents give different material properties**

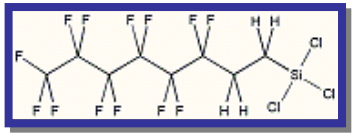


Polyester granules

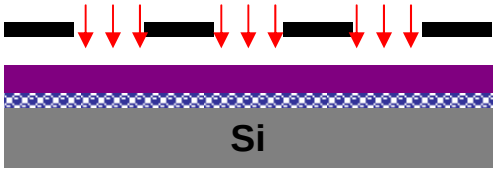


In Vitro PHB Synthesis

Molecular vapor deposition FOTS



Put down photoresist



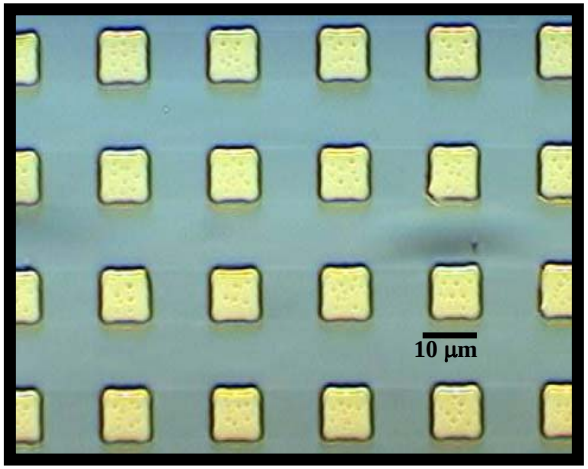
UV exposure

Remove photoresist

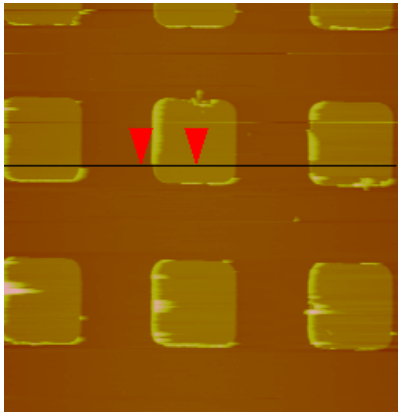
Au evaporation & Lift off

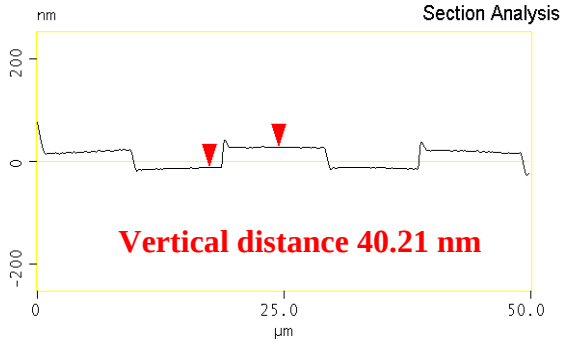
Au patterned surface

Optical micrograph of 10 μm x 10 μm Au arrays

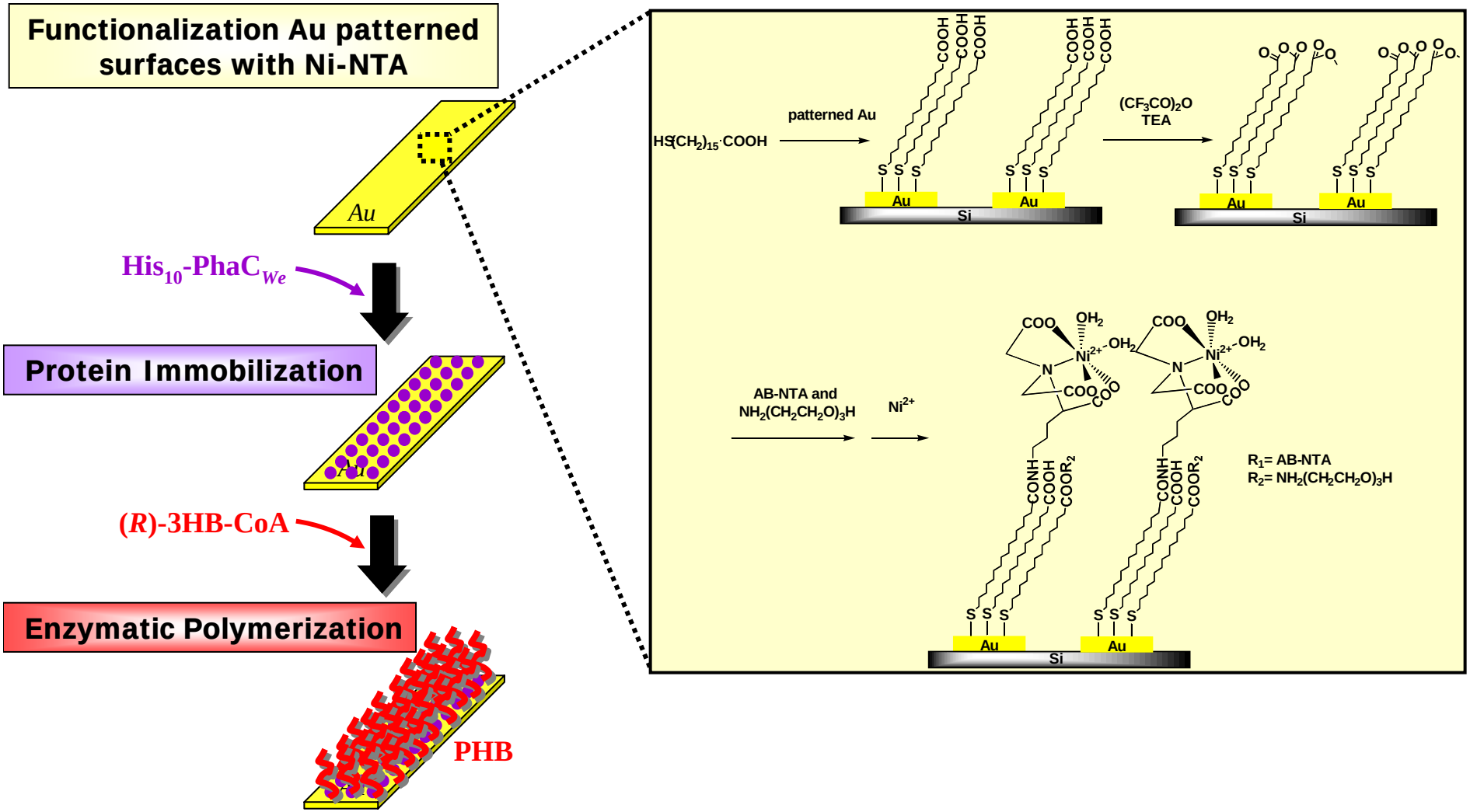


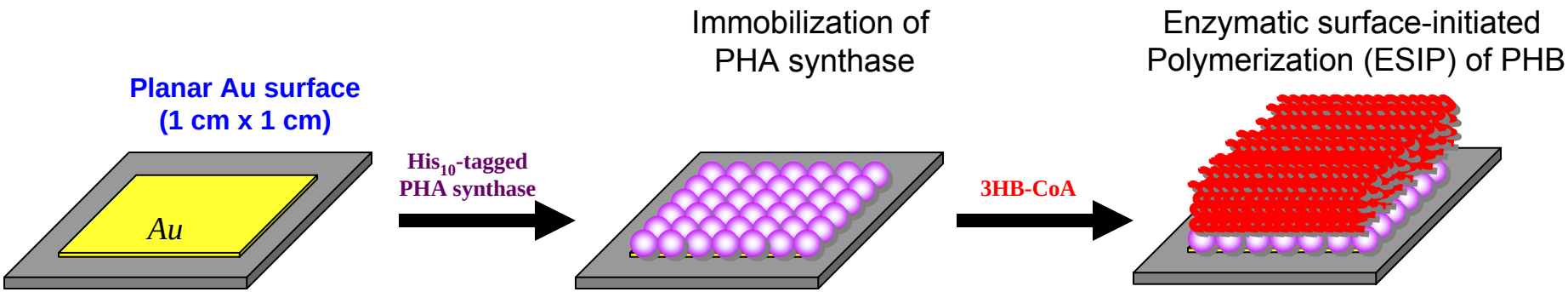
AFM analysis



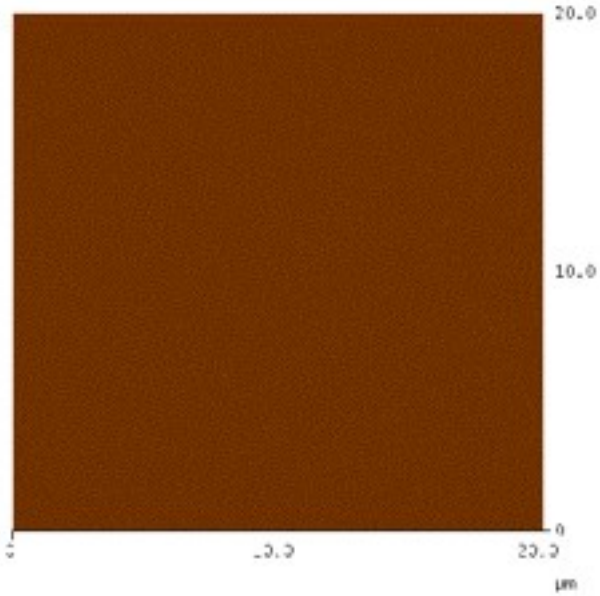


Bionanofabrication of PHB polymer on Au patterned surfaces

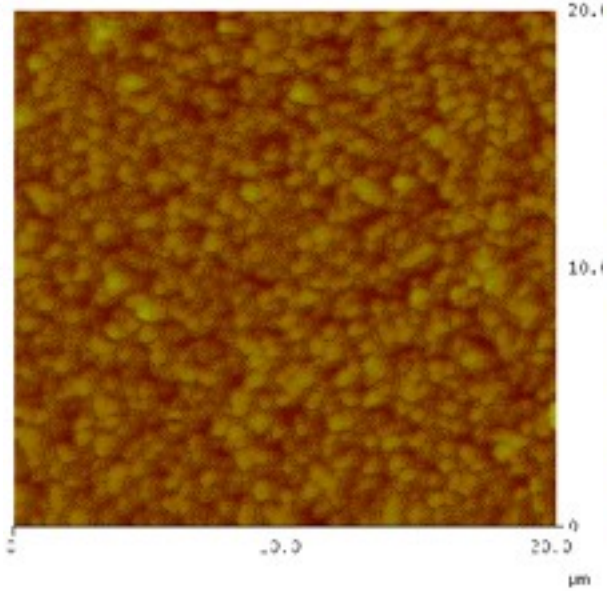




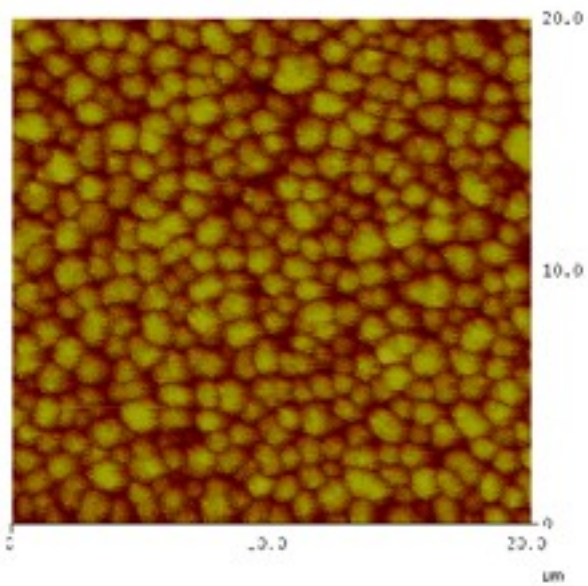
Unmodified planar Au



Au/PHB

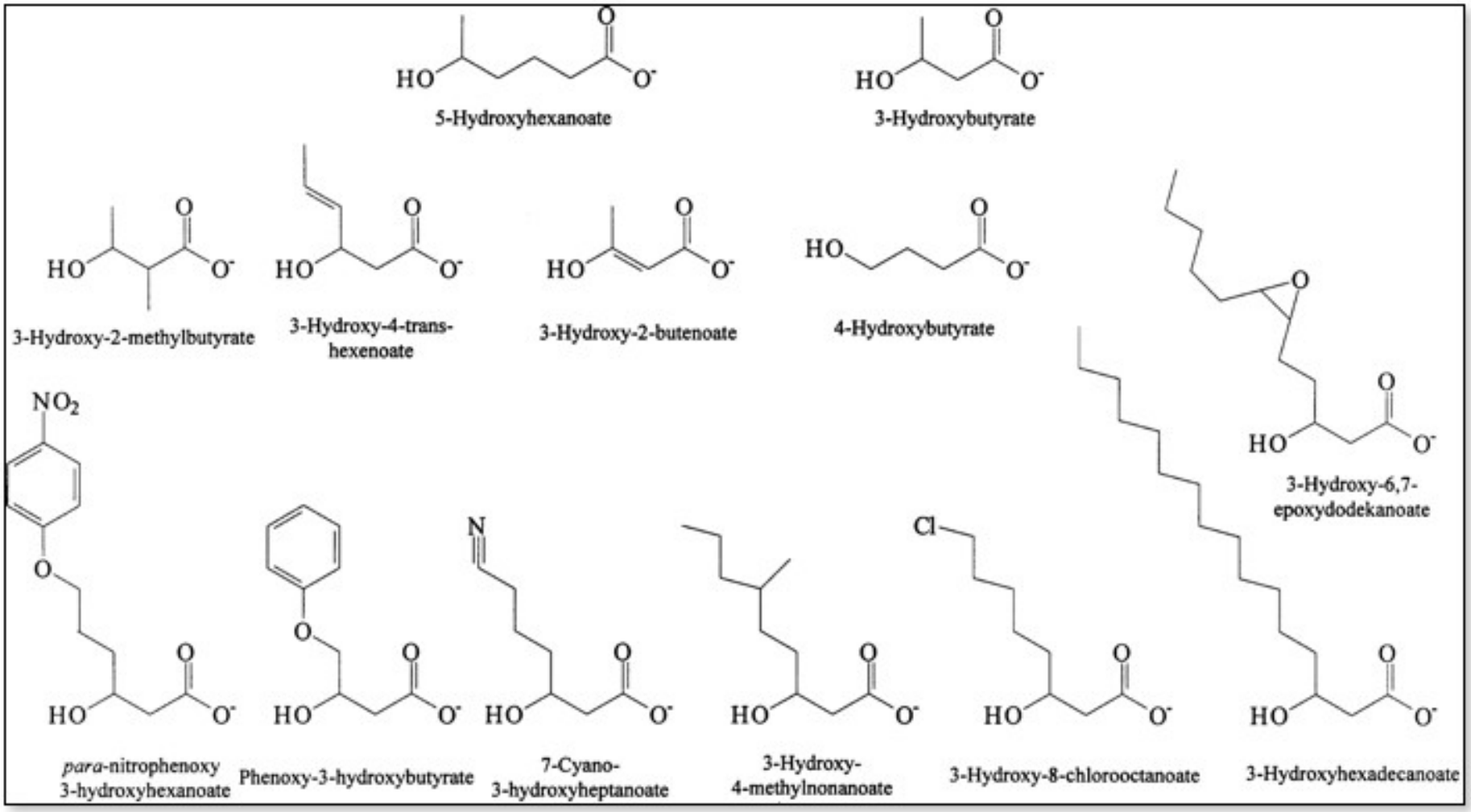


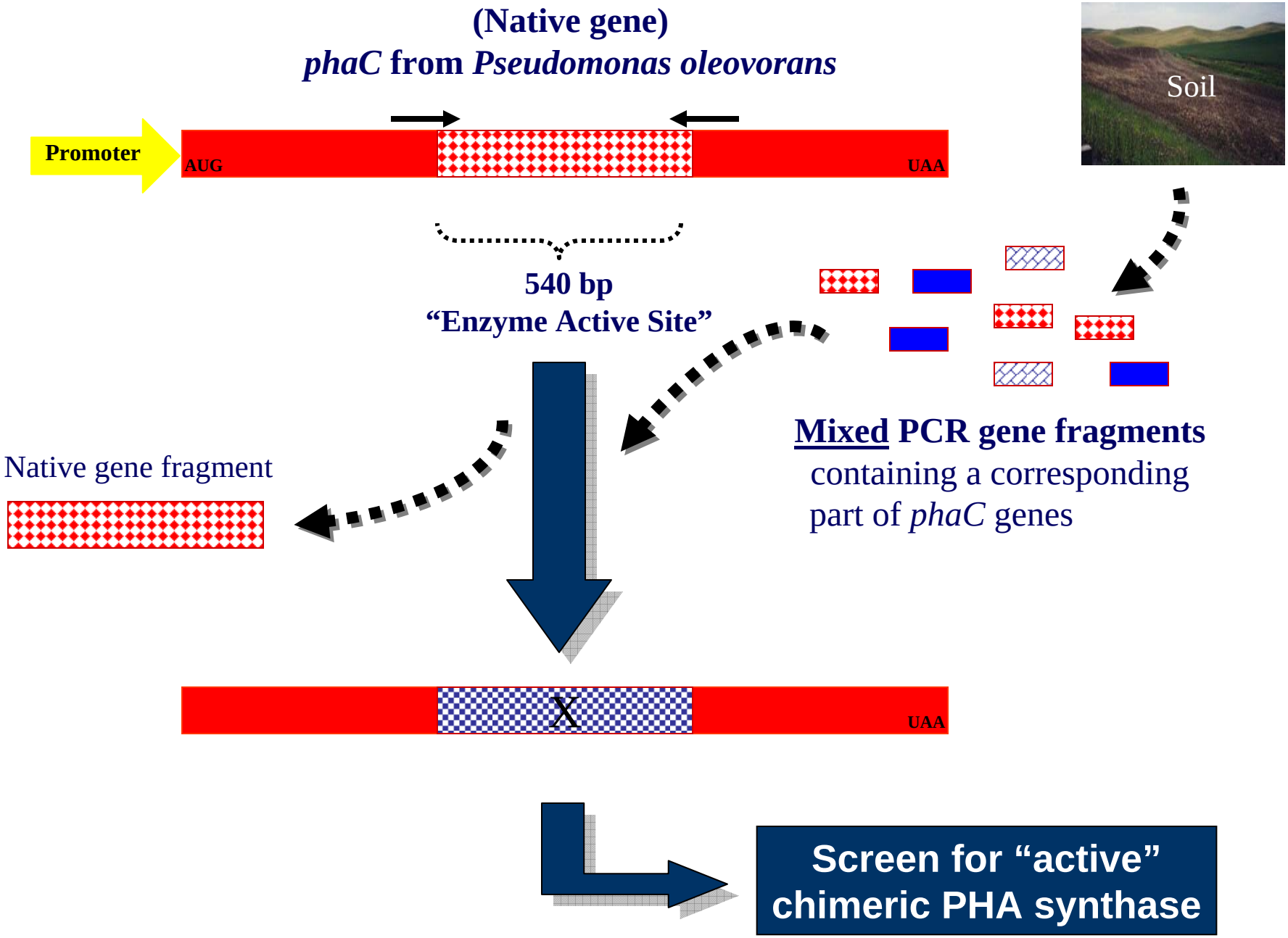
Au/PHB/BSA

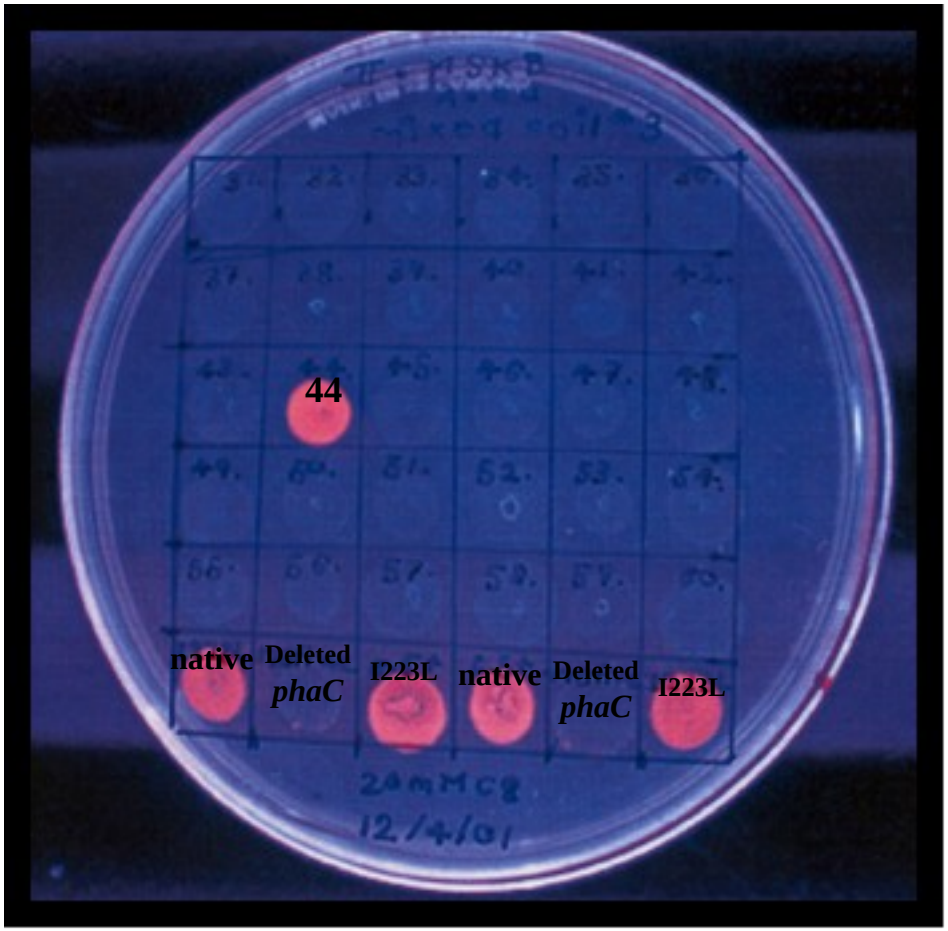


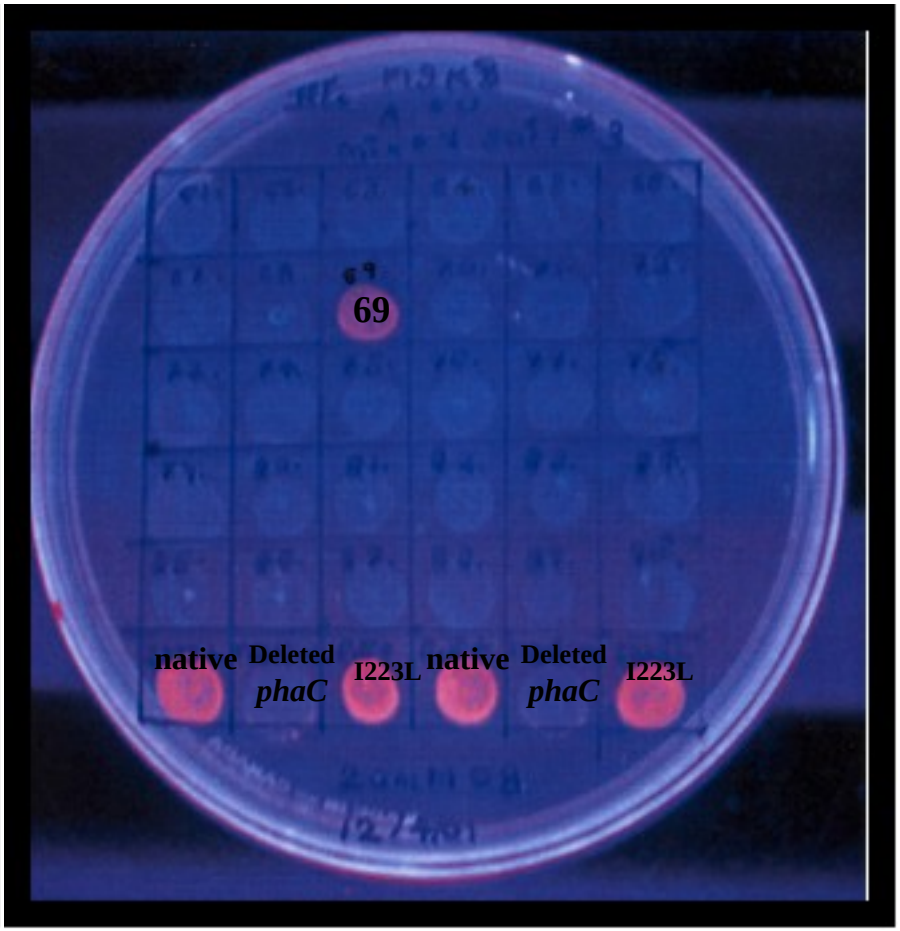
Keep that in mind

Various PHA Monomeric Constituents Found in Nature

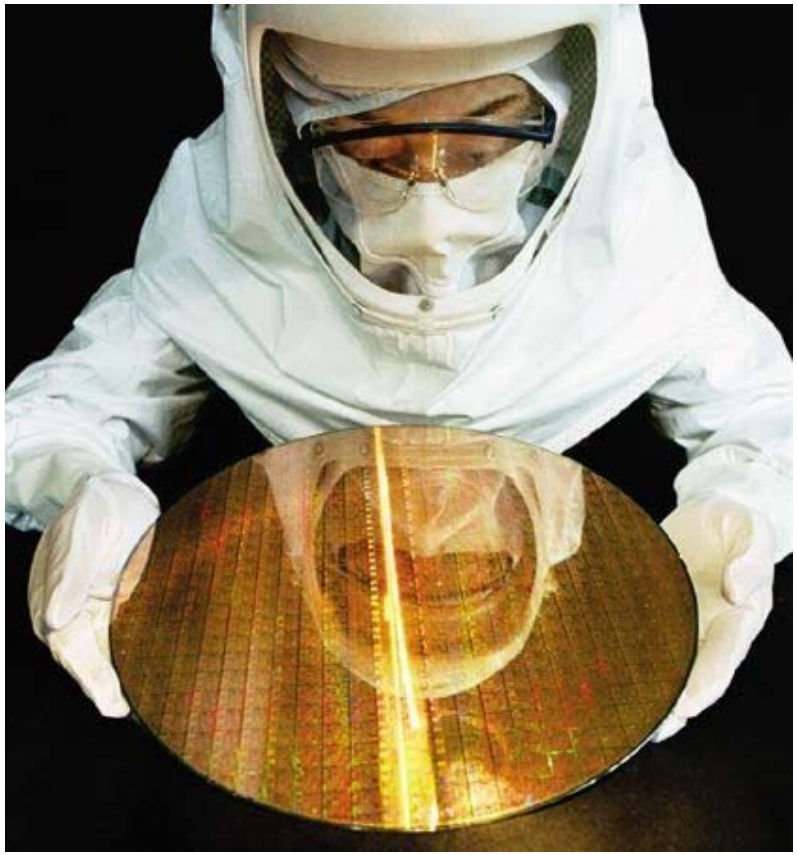


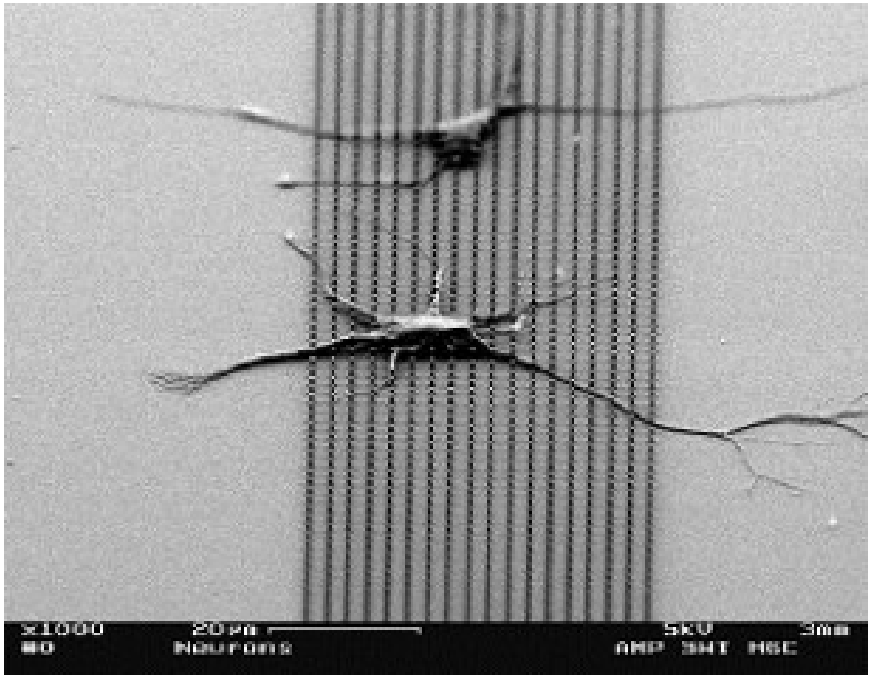

(Native gene)
phaC from *Pseudomonas oleovorans*
Soil
Promoter
AUG
UAA
540 bp
"Enzyme Active Site"
Mixed PCR gene fragments
containing a corresponding
part of *phaC* genes
Native gene fragment
X
UAA
Screen for "active"
chimeric PHA synthase

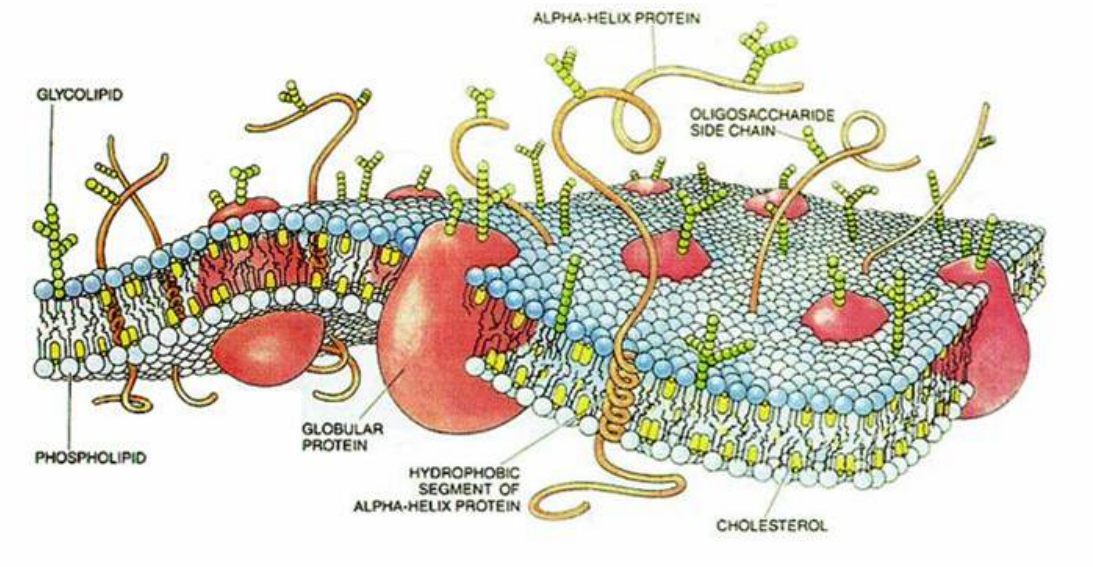

44
native
Deleted
phaC
I223L
native
Deleted
phaC
I223L
12/4/01


69
native
Deleted
phaC
I223L
native
Deleted
phaC
I223L

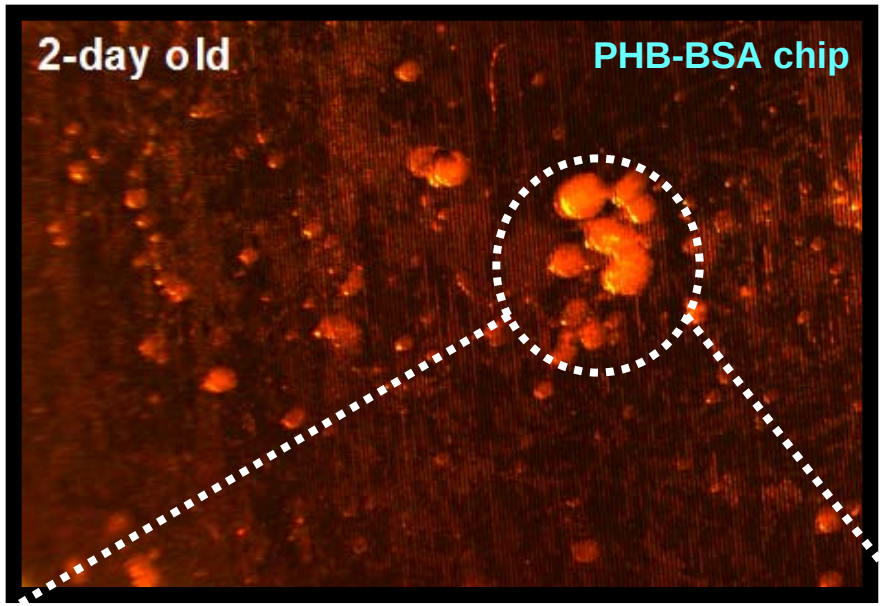
Is this useful?

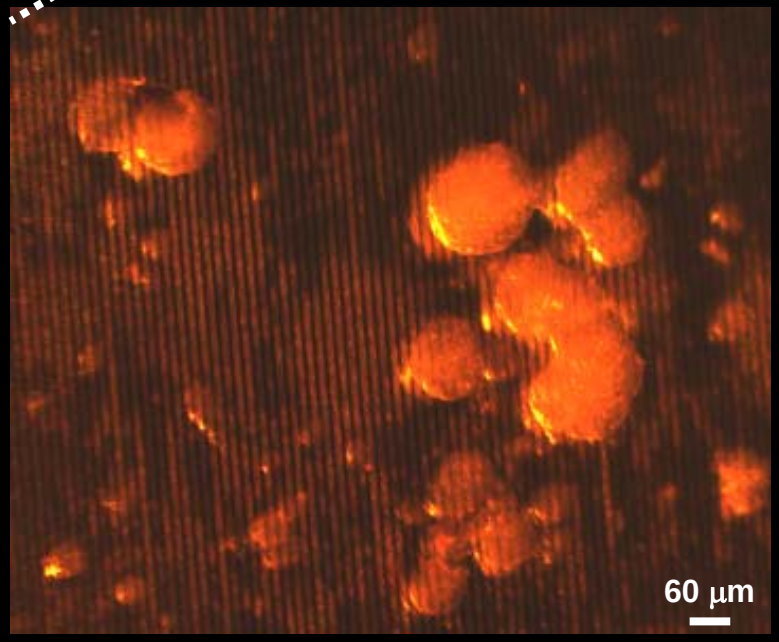


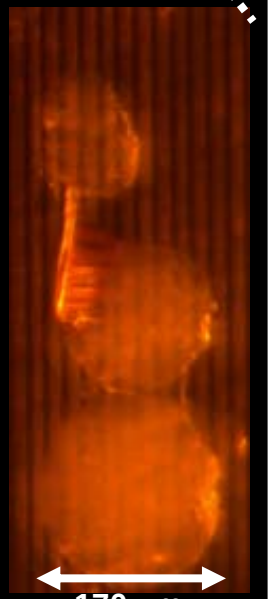

x1000
20μm
5kV
3mm
WD
Neurons
AMP SHT MSC


ALPHA-HELIX PROTEIN
GLYCOLIPID
OLIGOSACCHARIDE
SIDE CHAIN
GLOBULAR
PROTEIN
PHOSPHOLIPID
HYDROPHOBIC
SEGMENT OF
ALPHA-HELIX PROTEIN
CHOLESTEROL

No cell attachment observed



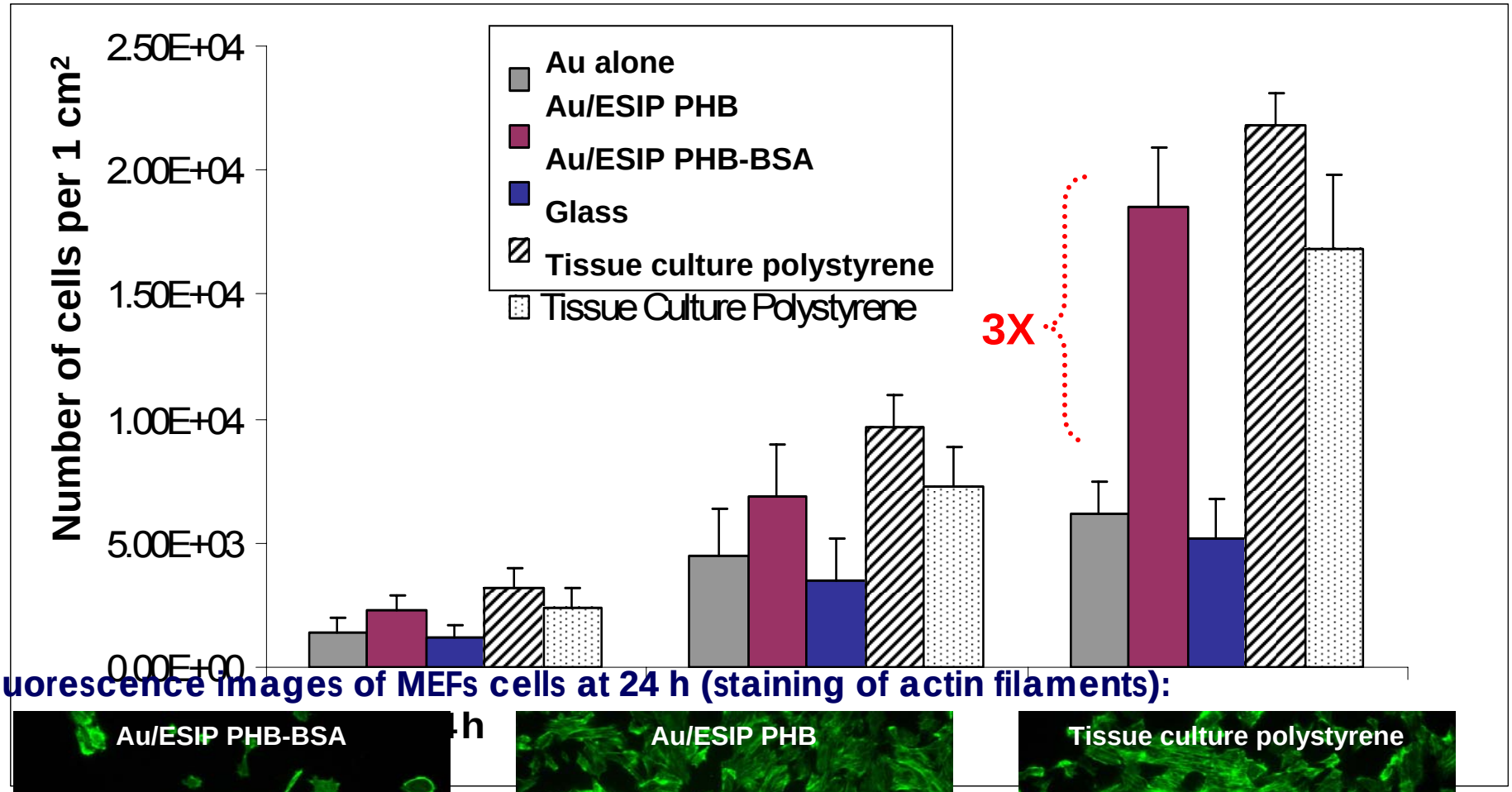




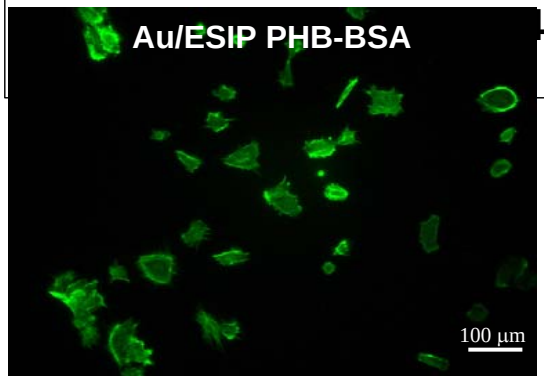
Non-differentiated ES cells have round shape morphology

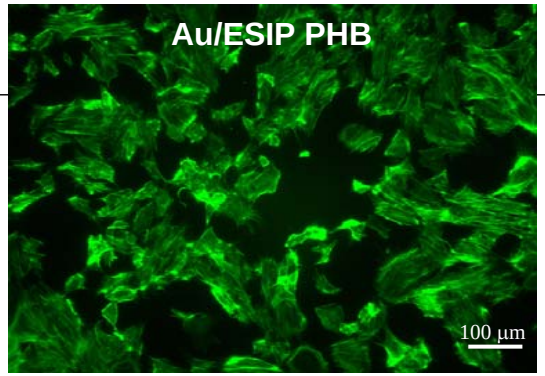
Biofabricated PHB-BSA surface may be used as a novel biocompatible surface for culturing stem cells.

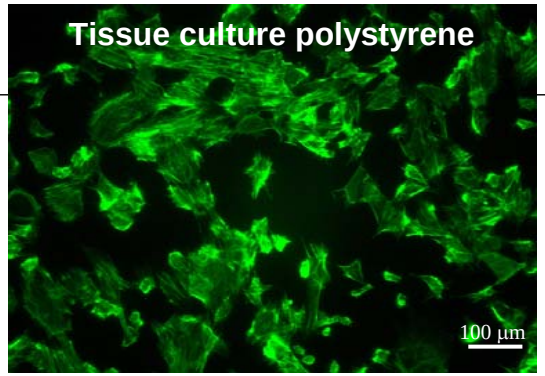
Cell Adhesion and Proliferation of Mouse Embryonic Fibroblasts (MEFs)



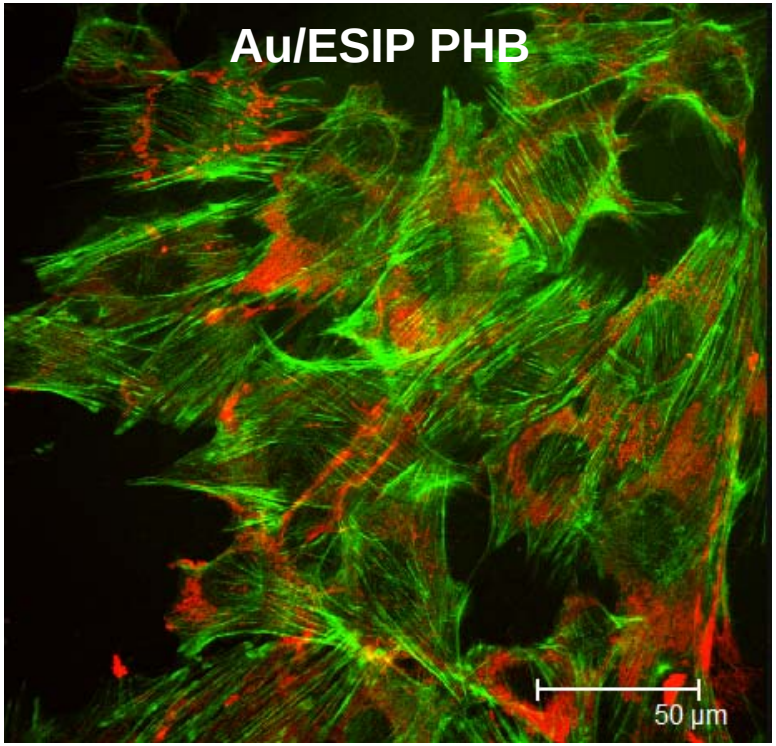
Fluorescence images of MEFs cells at 24 h (staining of actin filaments):

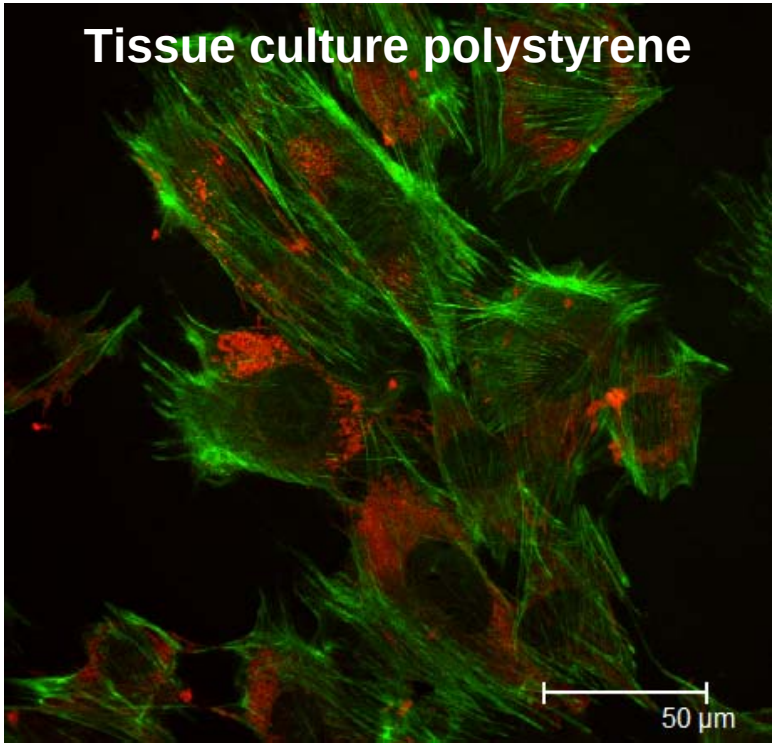






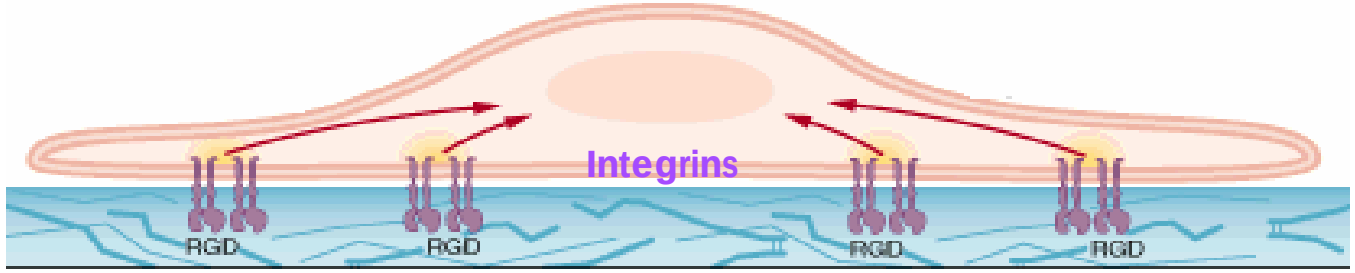
Fibronectin Distribution and Actin Filament in MEF Cells





…The actin filaments were structured in fibrils showing co-localization with fibronectin…

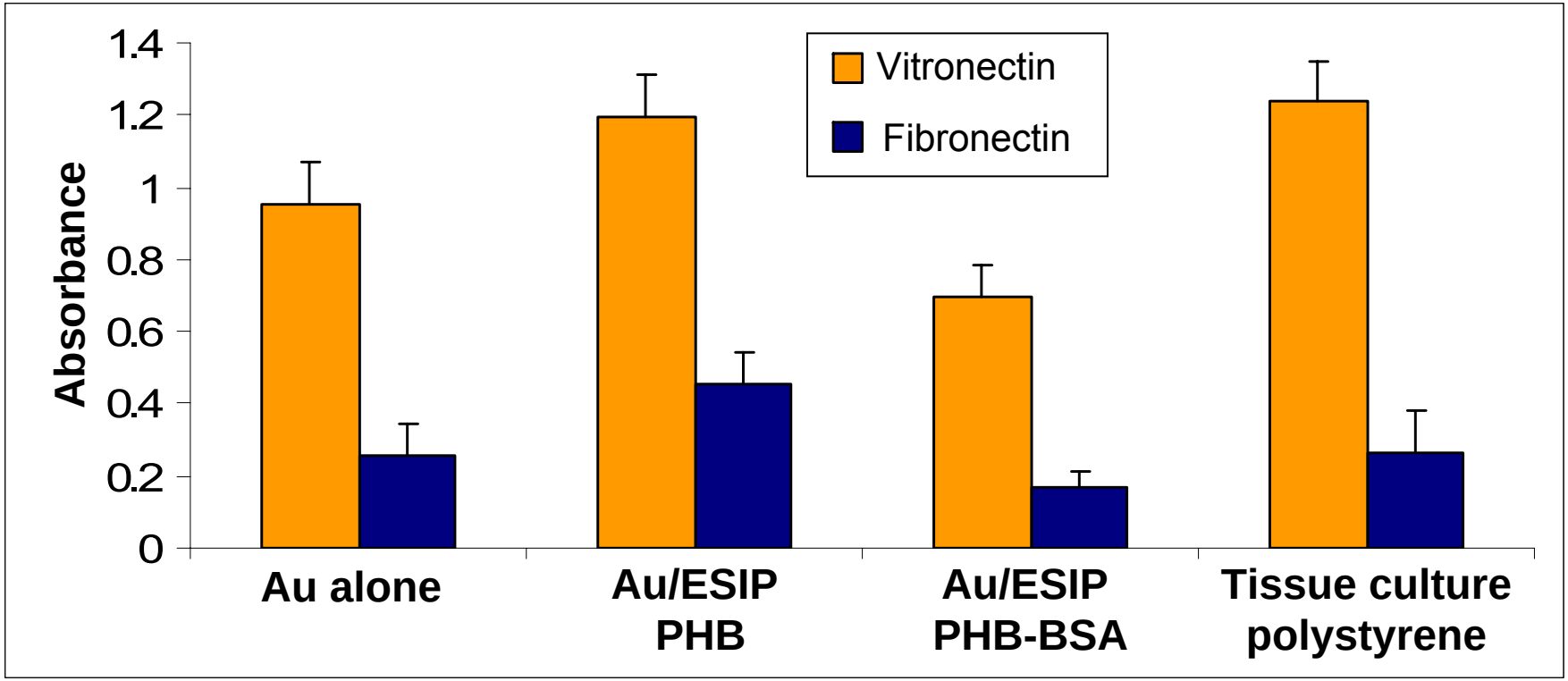
Chemical & mechanical signals
for survival and growth



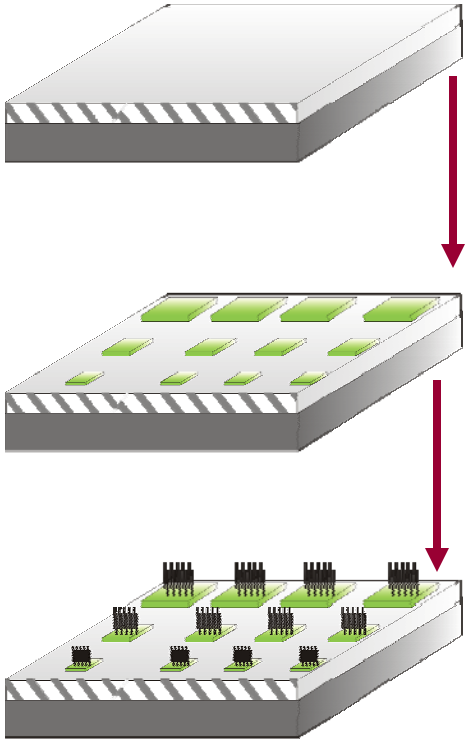
Extracellular Matrix (i.e. fibronectin)

What influence the attachment and growth of cells on the fabricated PHB surface ?

Measurement of Vitronectin and Fibronectin Adsorption from the Cell Culture Media Using ELISA

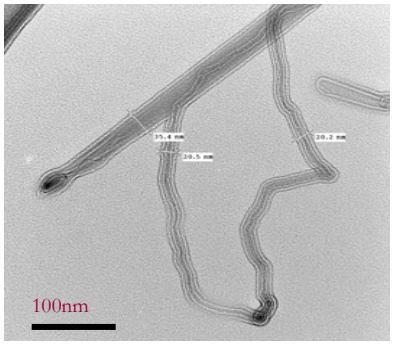


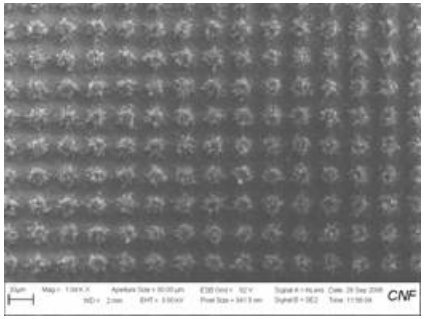
Fabrication

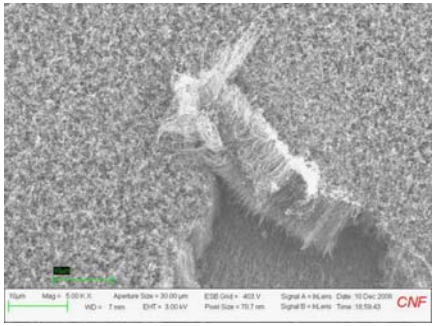


Photolithography
Ni 2nm

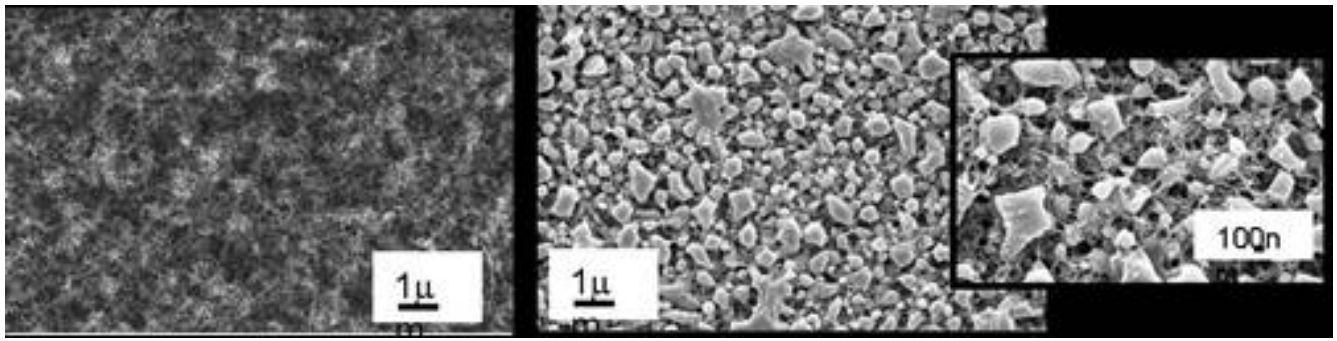
Chemical
Vapor
Deposition (C_2H_4)

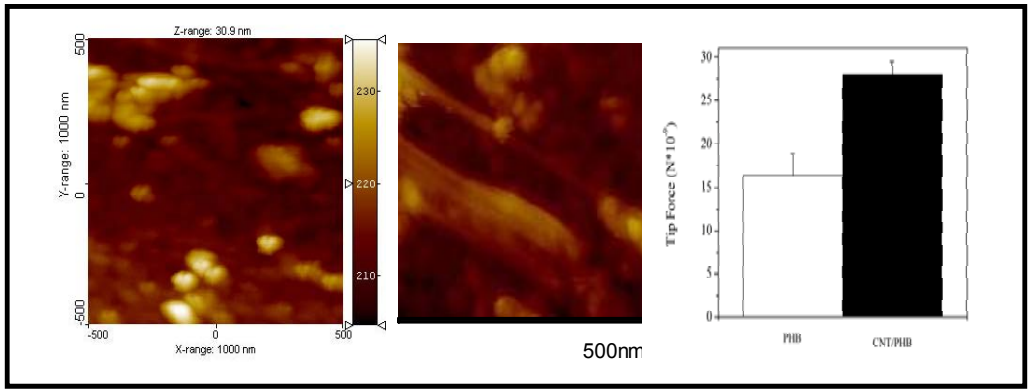


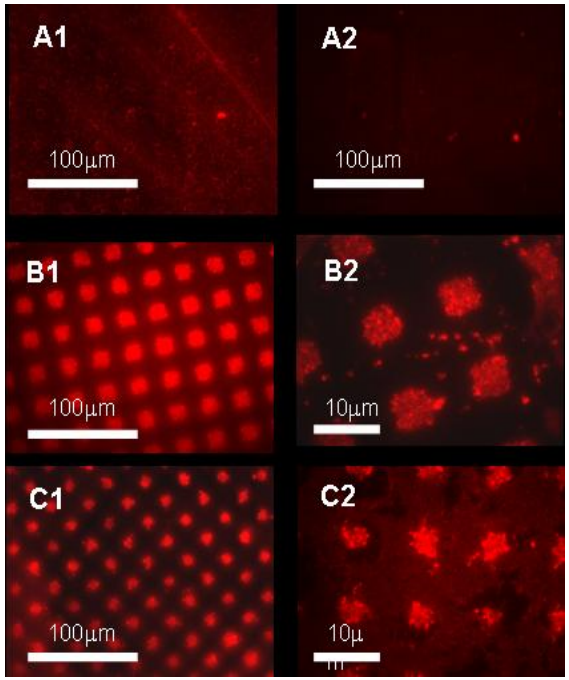




Carbon Nanotubes: *in situ* PHB growth

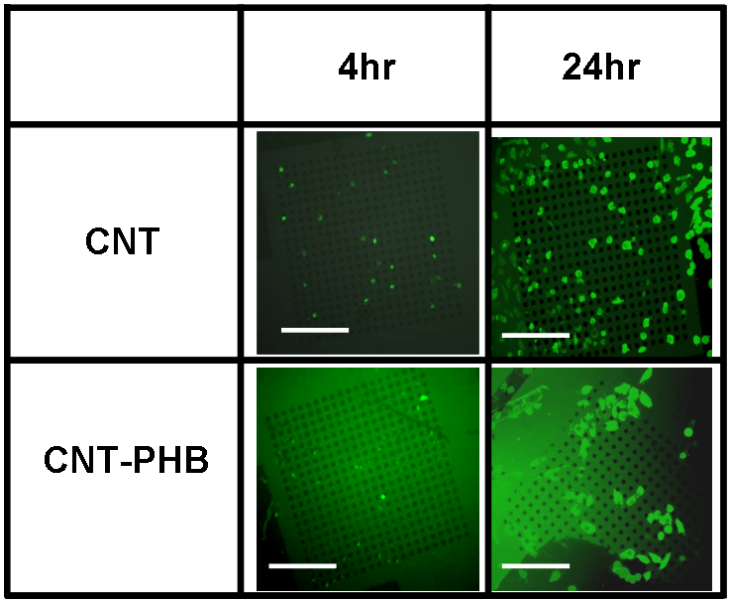




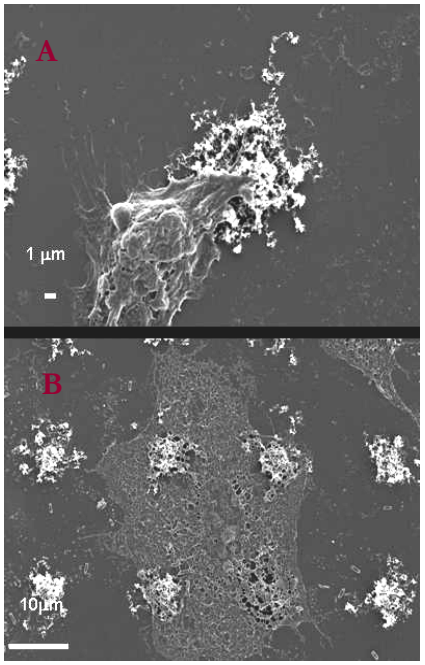


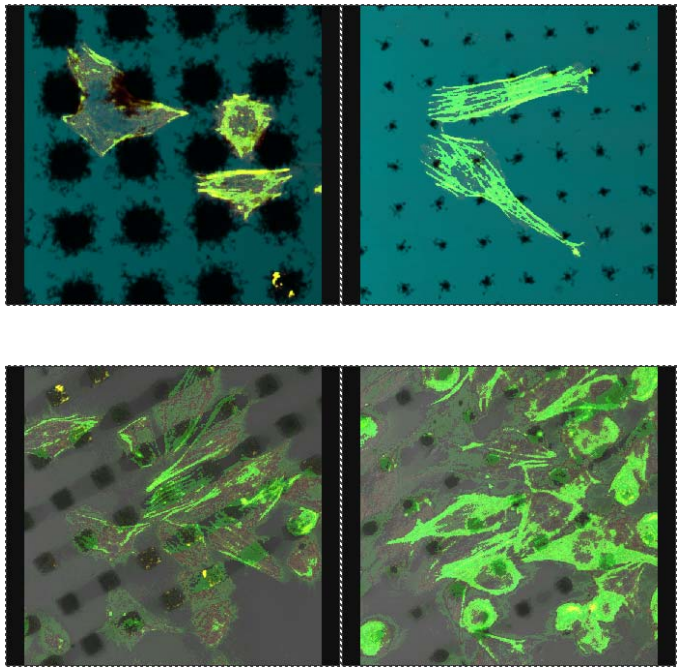
Carbon Nanotubes-PHB Osteoblast scaffold

Proliferation

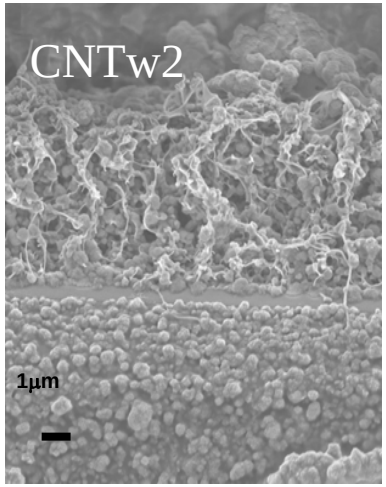


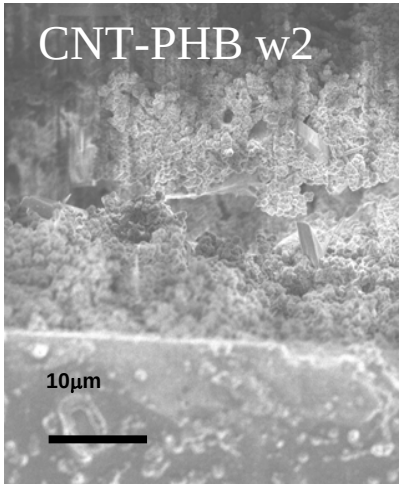
Morphology

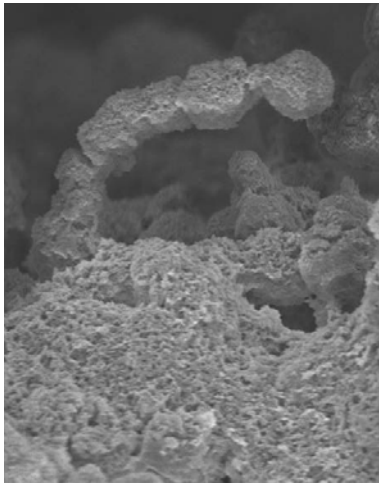


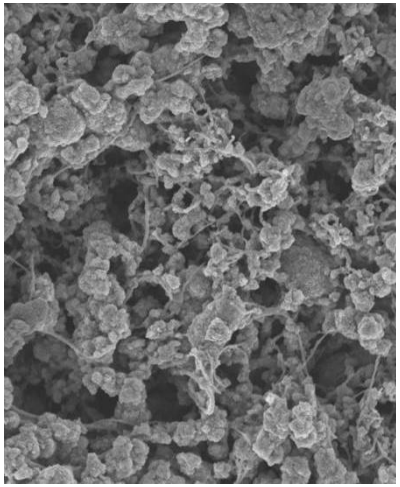


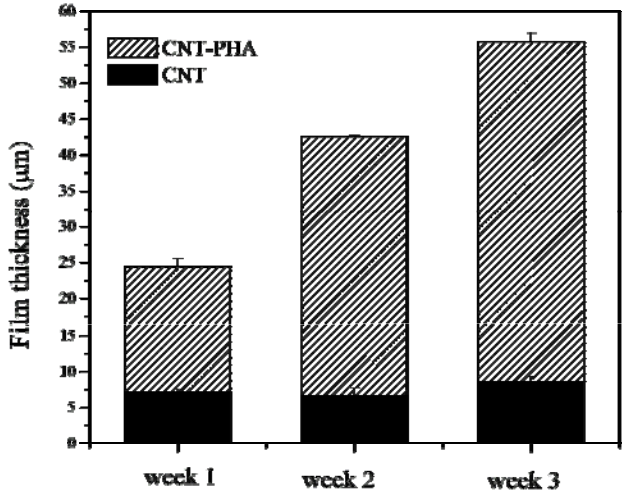
Bone formation on carbon nanotubes-PHB

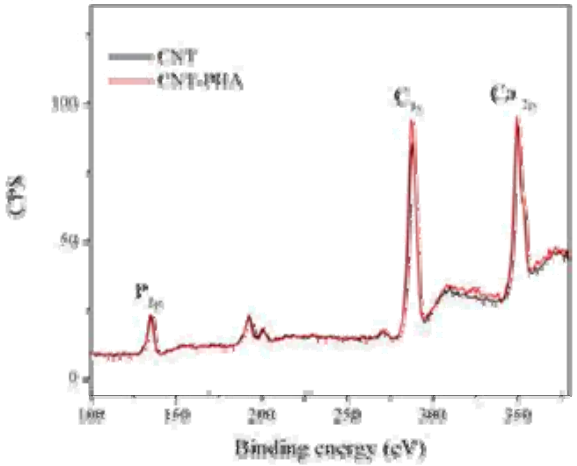


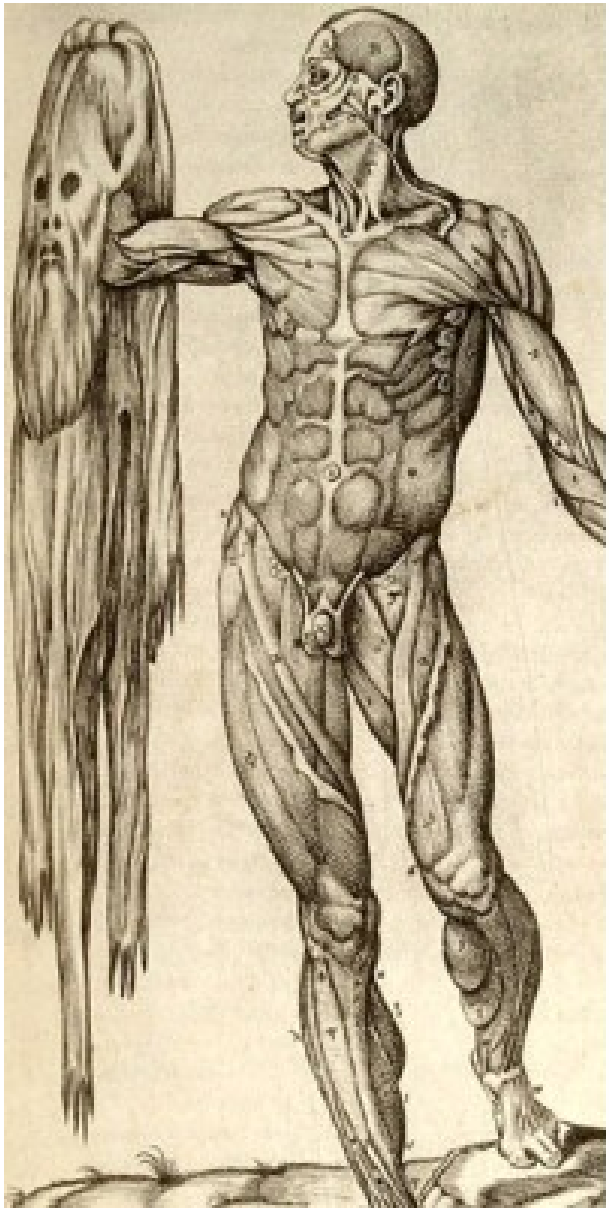


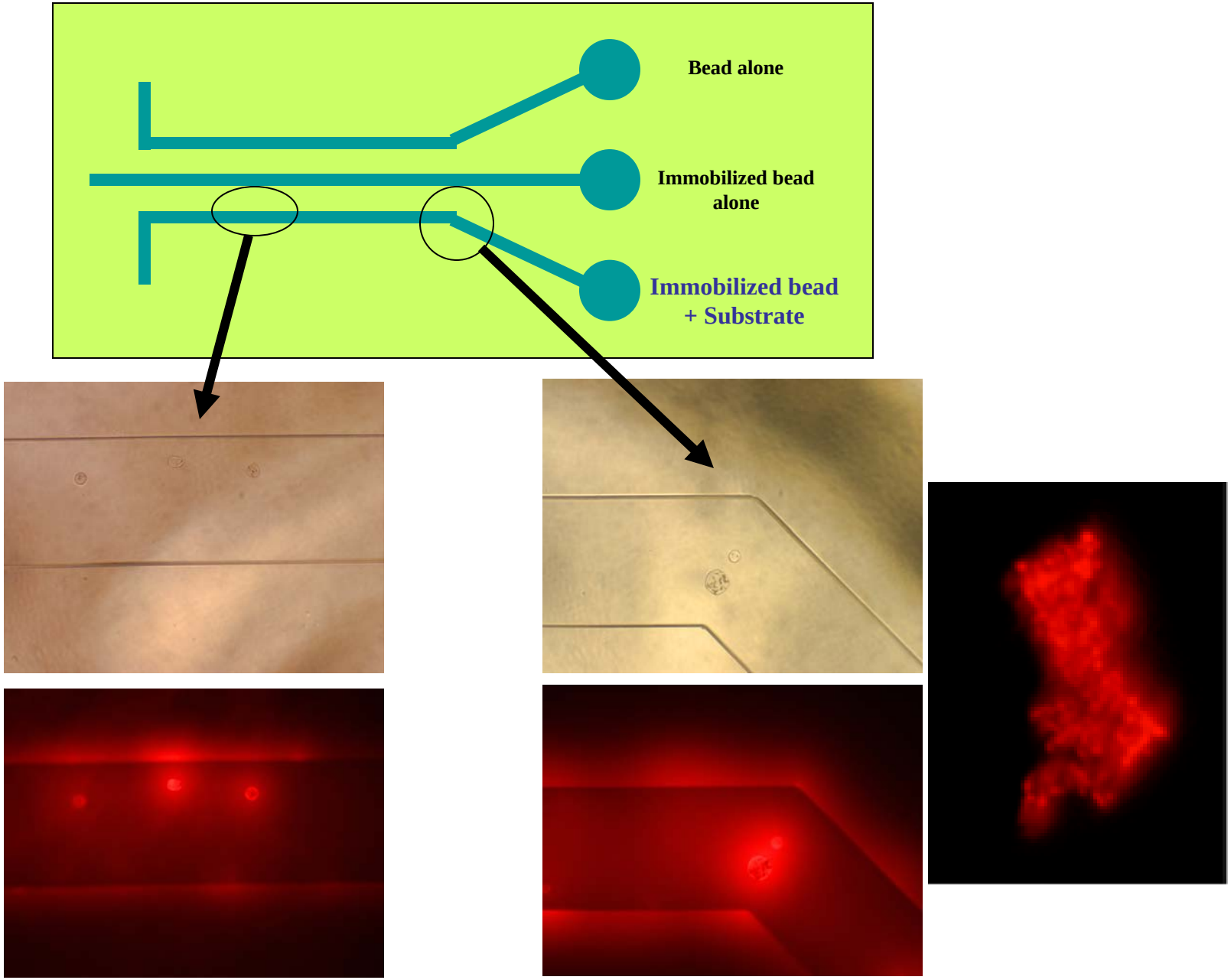


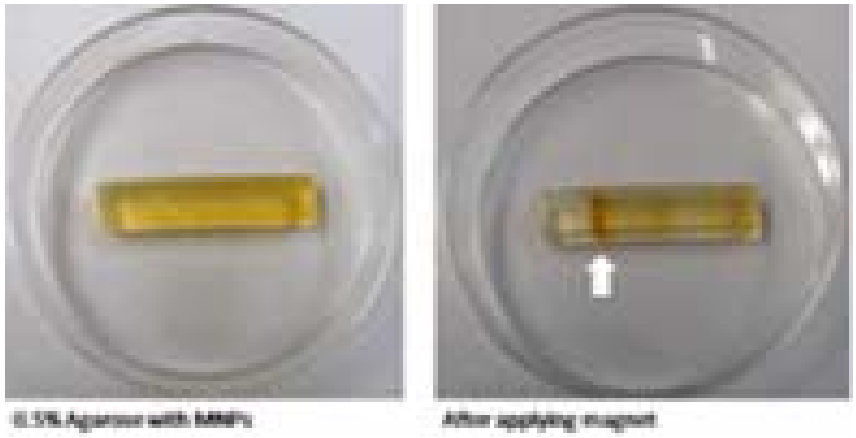


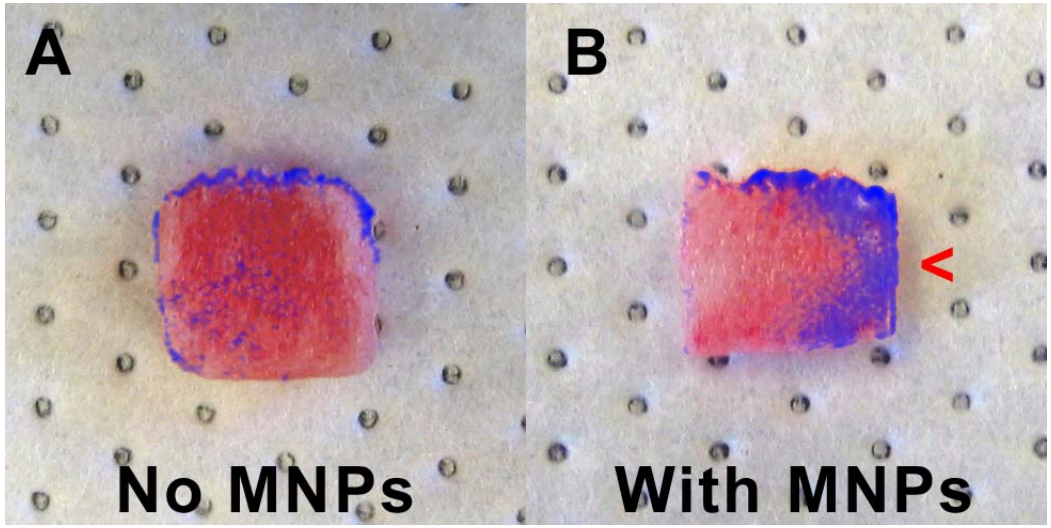







Bead alone
Immobilized bead alone
Immobilized bead + Substrate


0.5% Agarose with MNPs
After applying magnet


A
B
No MNPs
With MNPs

What about the body?

Too Small to See

- 1 & 2
- Wichita
- UC Santa Barbara

NANOZC

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