Nanotechnology in the life sciences

A FRONTIS LECTURE SERIES

organized by

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Nanotechnology in the life sciences

February 13	13:30	Pieter Stroeve-Size, measurement and sensing
	14:30	Mieke Kleijn (WUR)- Surface forces using AFM
February 20	13:30	Pieter Stroeve- (Bio)materials
	14:30	Ernst Sudholter (WUR)- Hybrid organic semiconductor FETs
February 27	**13:30**	**Pieter Stroeve- Self-assembly of molecular structures**
	14:30	**Richard Schasfoort (U Twente)- Surface modification and microfabrication strategies**
Friday, March 5	13:30	Pieter Stroeve- Environment
	14:30	Keurentje (TU Eindhoven)- Micellar systems for nanoscale engineering of reaction and separation processes
Friday, March 12	13:30	Pieter Stroeve- Life sciences and medicine
	14:30	Ton Visser (WUR)- Single-molecule fluorescence in microfluidic devices

Self-assembly of molecular structures

OUTLINE

- General comments
- Self-assembled monolayers (SAMs)
- Self-assembly of macromolecular structures on surfaces
- Layer-by-layer deposition of polyions
- Stamping
- Self-assembly of diblock polymers
- Self-assembly of macromolecules

Applications

- Catalysts
- Integrated circuits
- Data Storage
- Drug Delivery
- Sensors
- Medical Devices
- Biomaterials
- Nanoparticles
- Microfluidics
- Separation and purification

Self-assembly can be influenced by

- Interface
- Reaction
- Electric field
- Flow
- Temperature
- Solvent
- Ionic strength
- pH

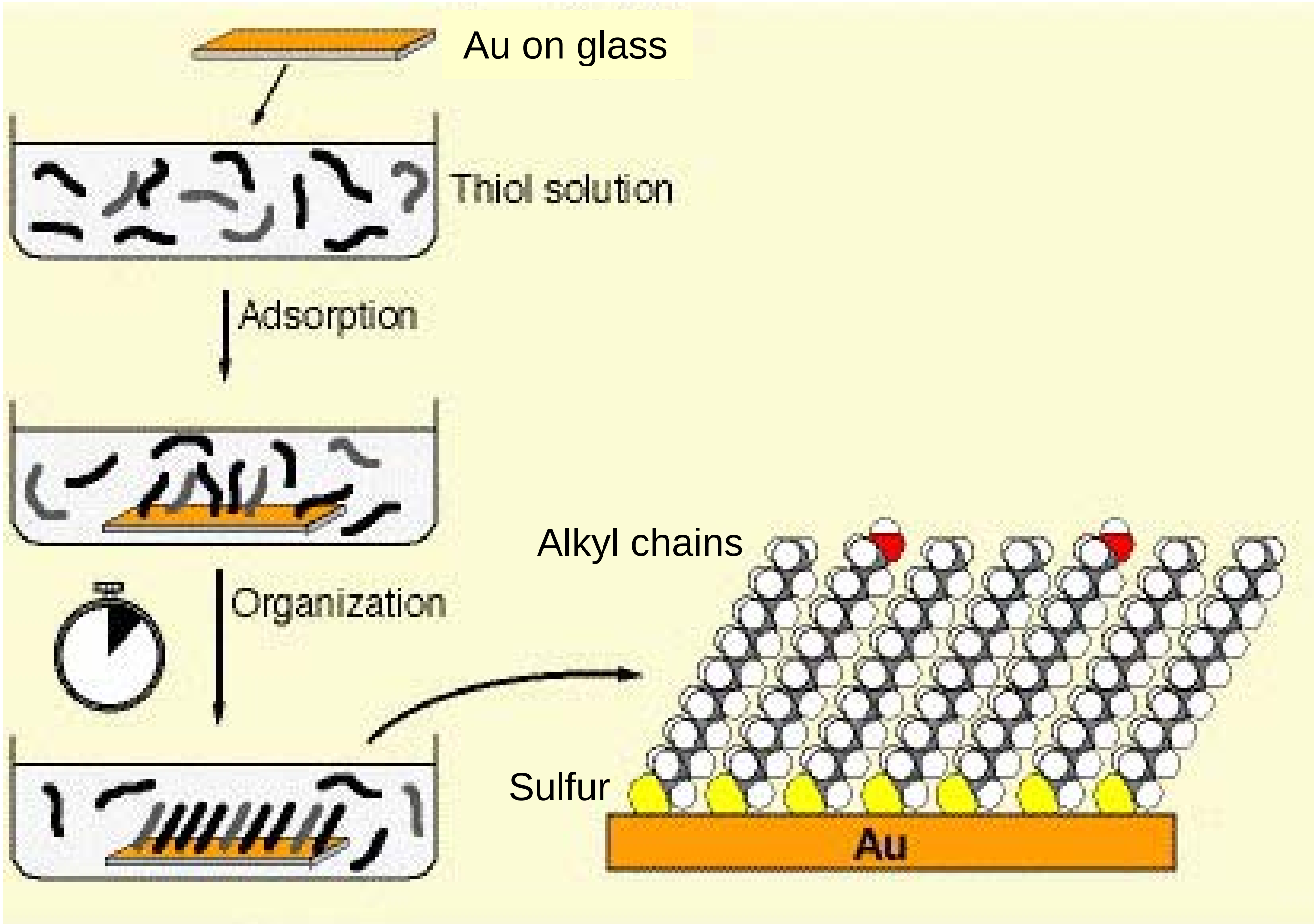
Self-assembly of molecular structures

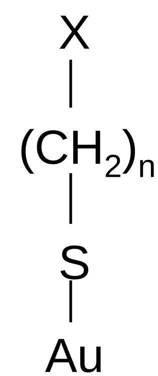
- ➔ Self-assembled monolayers (SAMs)
- Self-assembly of macromolecular structures on surfaces
- Layer-by-layer deposition of polyions
- Stamping
- Self-assembly of diblock polymers
- Self-assembly of macromolecules

Self-assembled monolayers

- ➔ Thiols on metals (Whitesides)
- Silanes on oxides (Sagiv)
- Alkenes and alkynes on silicon hydride (Sudholter)

Self-assembly of thiols on gold films





X = $-CH_3$, -OH, -COOH, $-SO_3^-$, $-PO_4H_2$, $N^+(CH_3)_3$, $-(OCH_2CH_2)_nOH$, ...

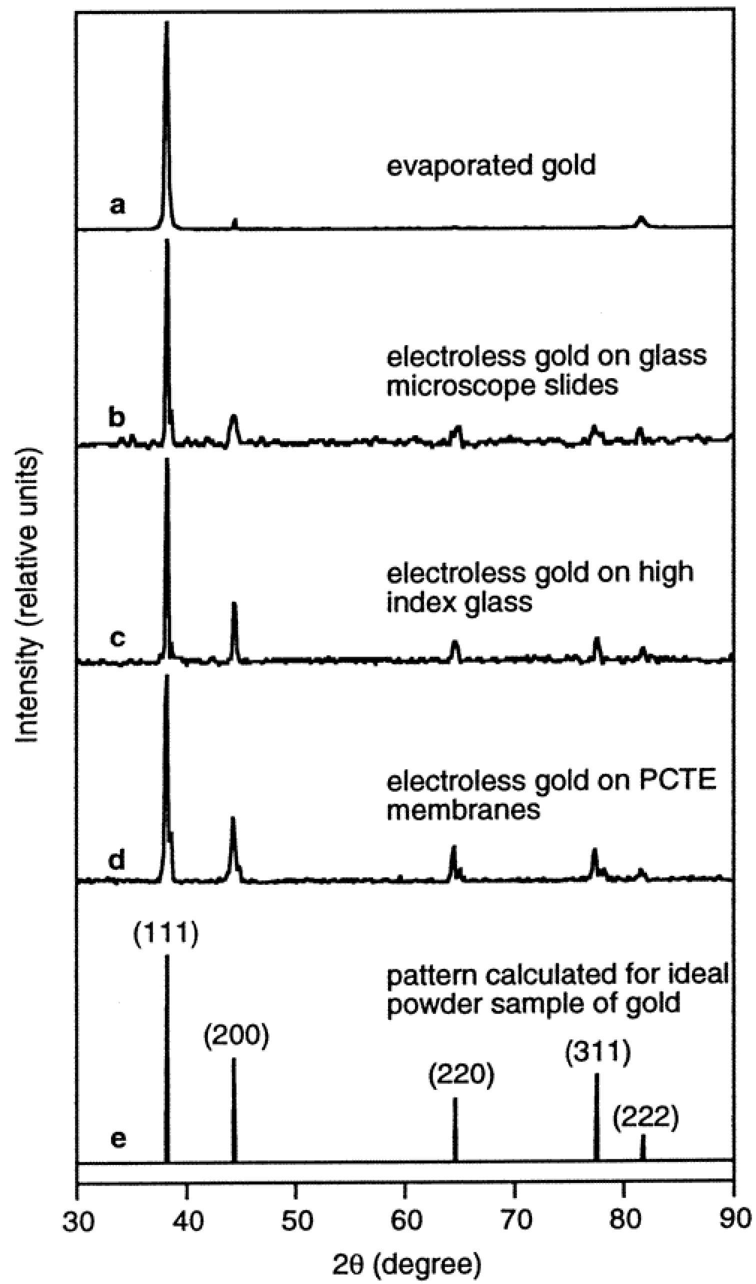
Gold is usually deposited by vacuum evaporation techniques.

Electroless gold is also of interest for complex geometries.

XRD data on gold: information on crystallographic planes

X-ray diffraction patterns of films of electroless gold and evaporated gold supported on a variety of substrates.

Hou, Stroeve et al., Langmuir 1998



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IR data on alkane thiols on gold: orientation of molecules

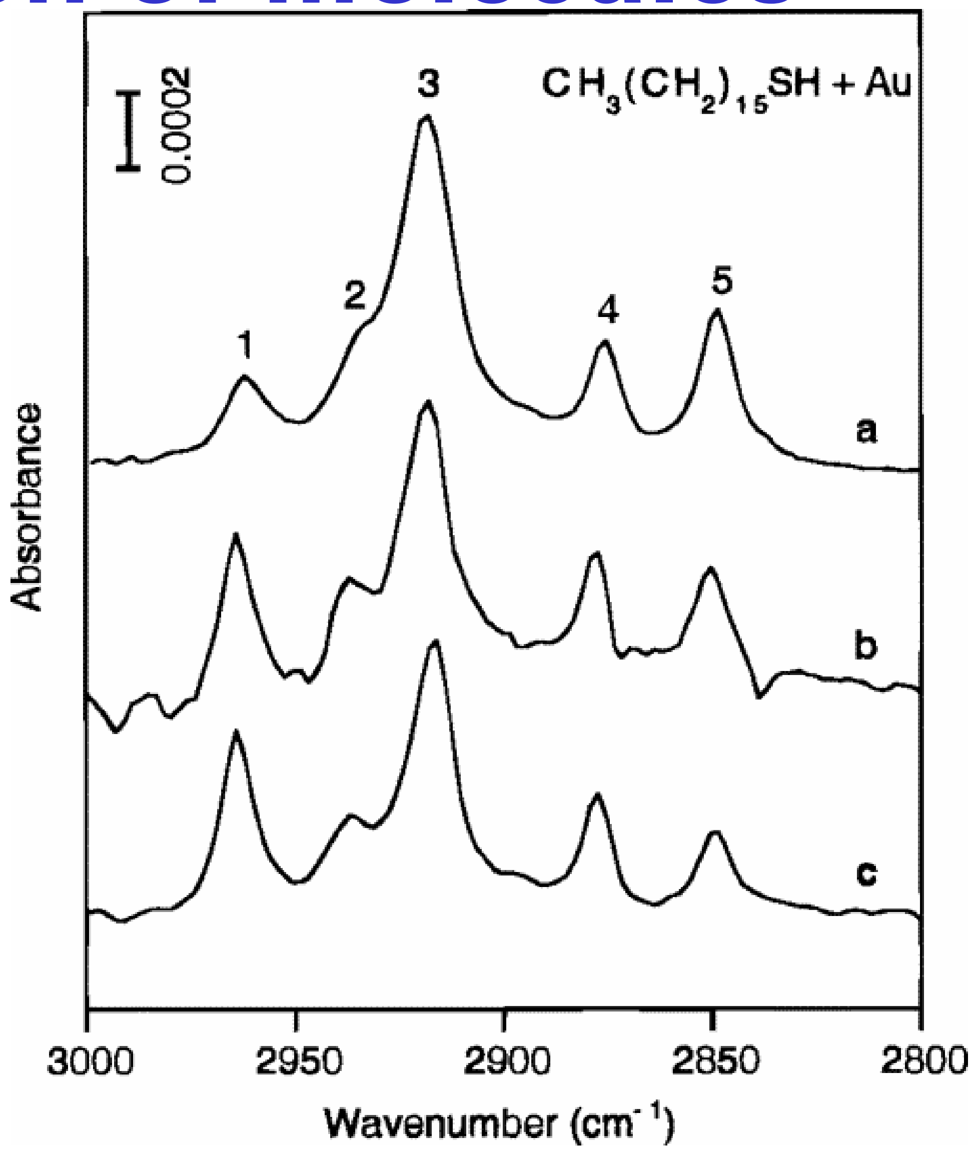
Grazing-angle infrared spectra of SAMs formed from $CH_3(CH_2)_{15}SH$ on

(a) evaporated gold,

(b) electroless gold on glass microscope slides, and

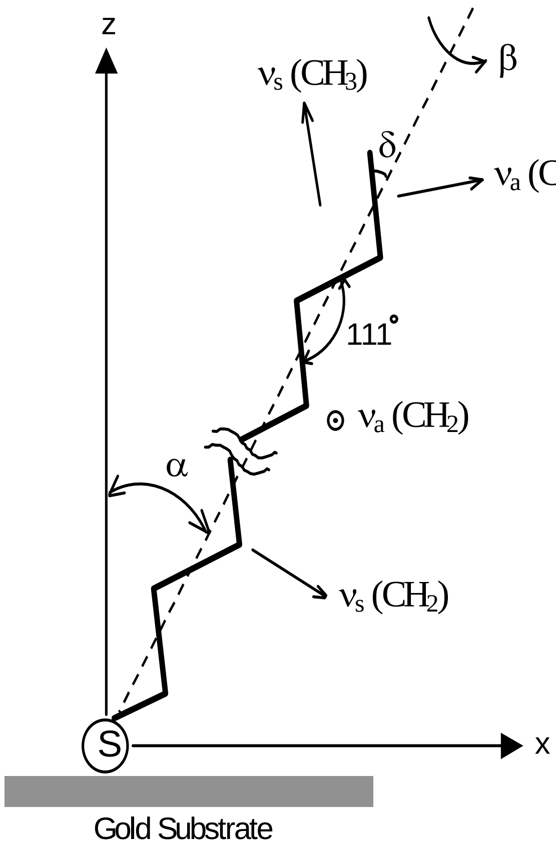
(c) electroless gold on high-index glass.

Hou, Stroeve et al., Langmuir 1998



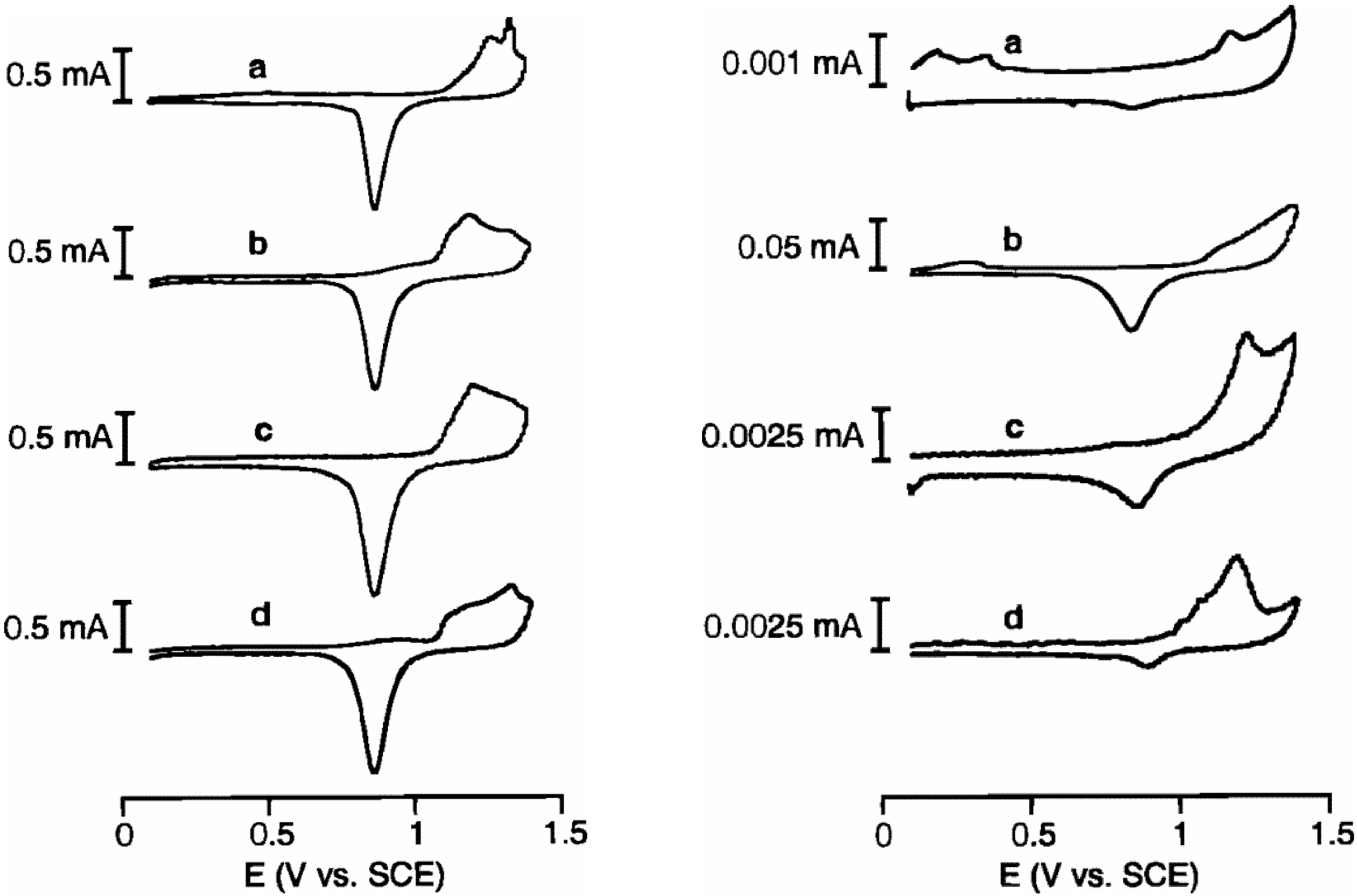
Thiol oriented with tilt angle alpha

Aliphatic chain within a SAM formed from an alkanethiol on a surface of gold. Directions of transition dipole moments corresponding to C–H stretching modes are shown. The projections of the transition dipole moments along the surface normal (z) are determined by the tilt angle (α) and twist angle (β) of the chain. In this diagram, α = 30° and β = 0°.



Cyclic voltammetry on gold and SAMs on gold in 0.1 M H_2SO_4:
(a) evaporated gold; (b) electroless gold on glass microscope slides;
(c) electroless gold on high index glass slides;

(d) electroless gold on PCTE membranes. **Hou, Stroeve et al., Langmuir 1998.**

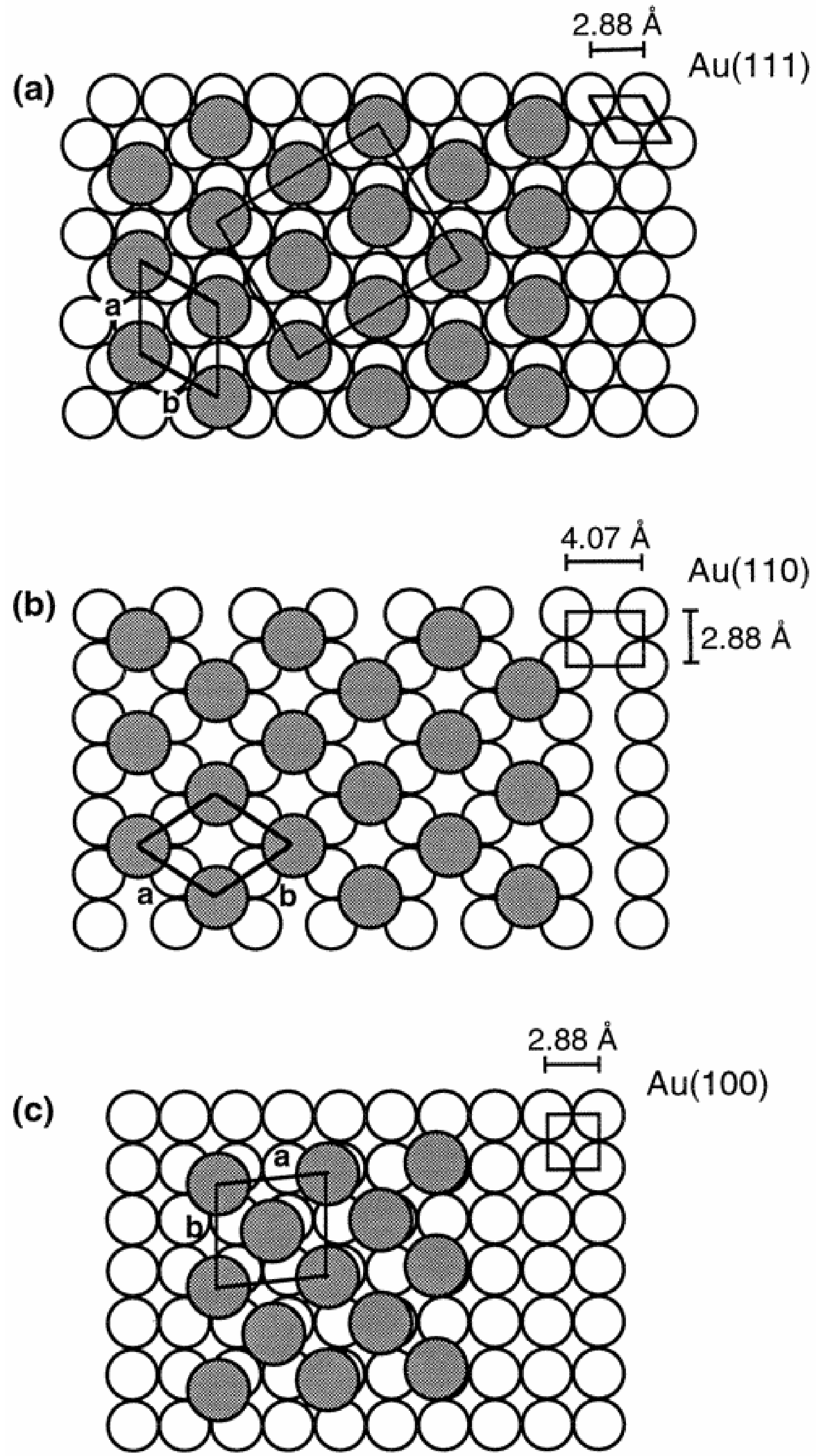


SAMs on gold

Alkanethiols on single crystals of gold. Open circles represent gold atoms, and shaded circles represent alkyl chains.

(a) Au(111). The smaller rhombus shows the Au(111) lattice. The larger rhombus shows a unit mesh with ***a*** = ***b*** = 4.97 Å and α= 120 (angle between ***a*** and ***b***).
(b) Au(110). Also shown is a unit mesh with ***a*** = ***b*** = 4.99 Å and α = 109.5.
(c) Au(100). Also shown is an oblique mesh with ***a*** = ***b*** = 5.97 Å and α = 95.

Camillone et al, J. Chem. Phys., 1993. Hou, Stroeve et al., Langmuir 1998.



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Self-assembled monolayers (SAMs) on gold

- Molecules are close-packed (if C_{10} or greater)
- Crystallographic surface of gold determines packing
- Large choice of functional groups
- Template for assembly of macromolecules

Self-assembly of molecular structures

- Self-assembled monolayers (SAMs)
- ➔ Self-assembly of macromolecular structures on surfaces
- Layer-by-layer deposition of polyions
- Stamping
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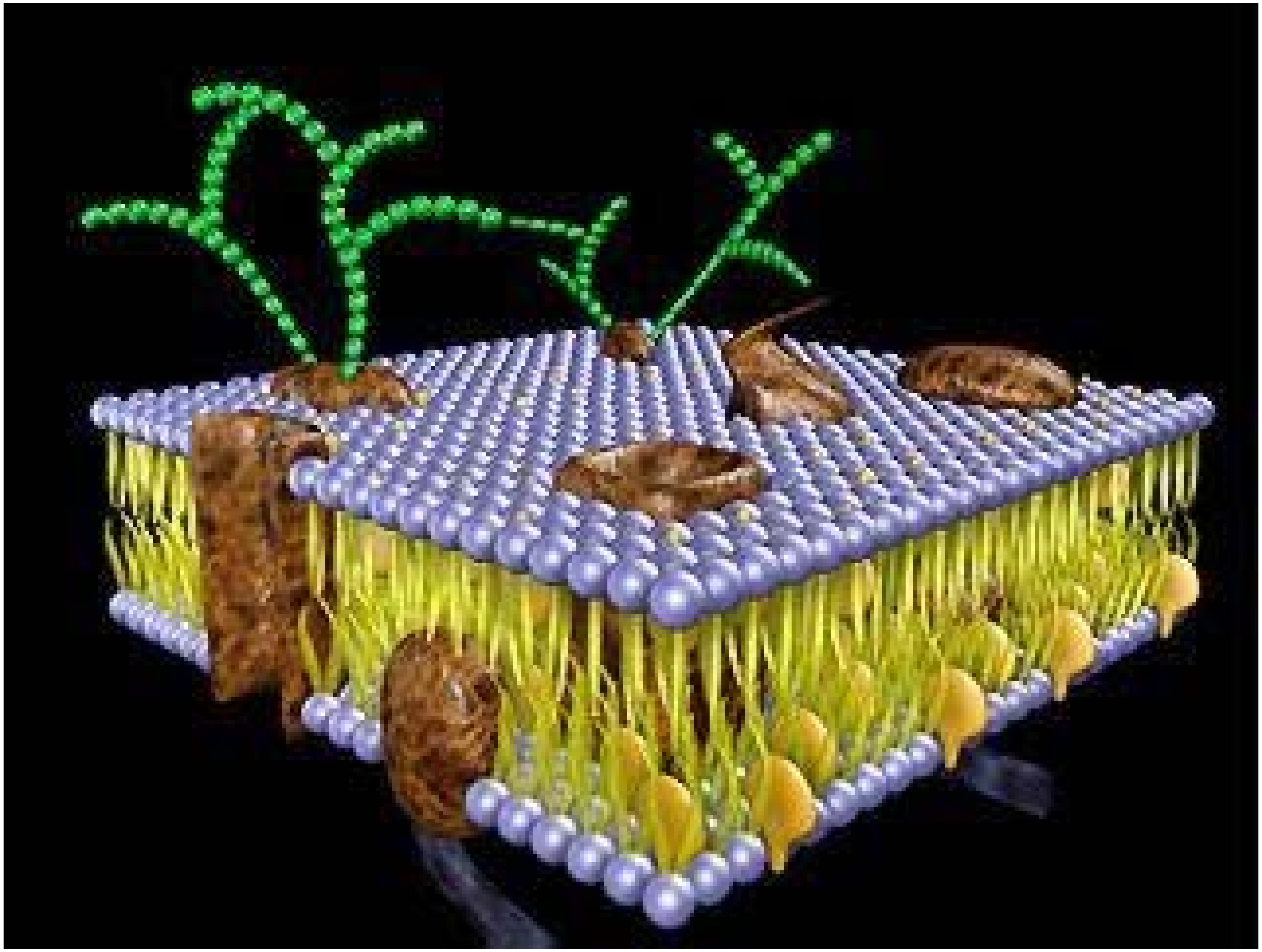
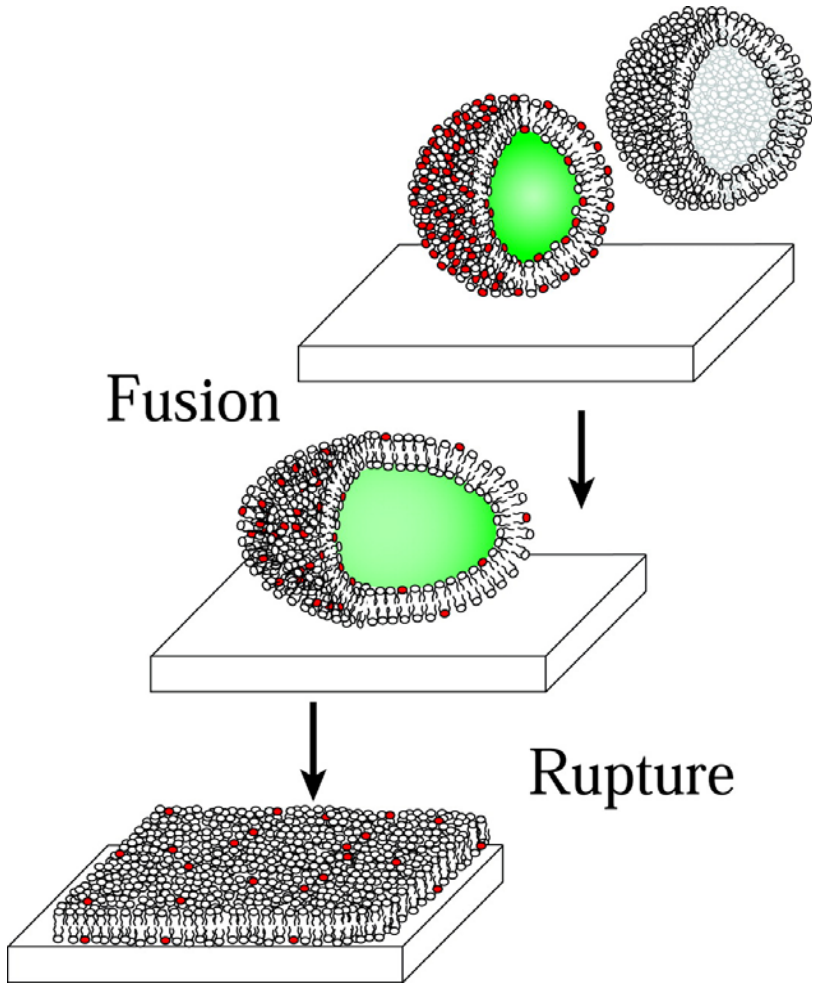
Example: the cell membrane- a macromolecular assembly



Supported lipid bilayers by vesicle fusion



H.M. McConnell,S. Boxer,
E. Sackman

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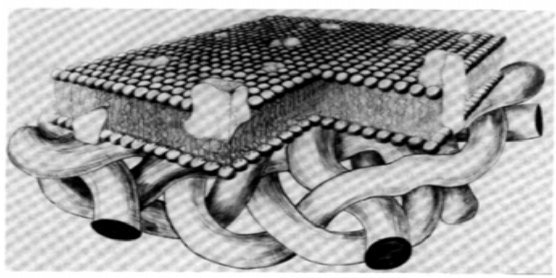
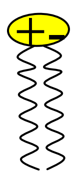
Lipid bilayer / peptide on SAM substrate → biosensor



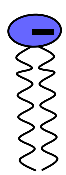
Red blood cell membrane

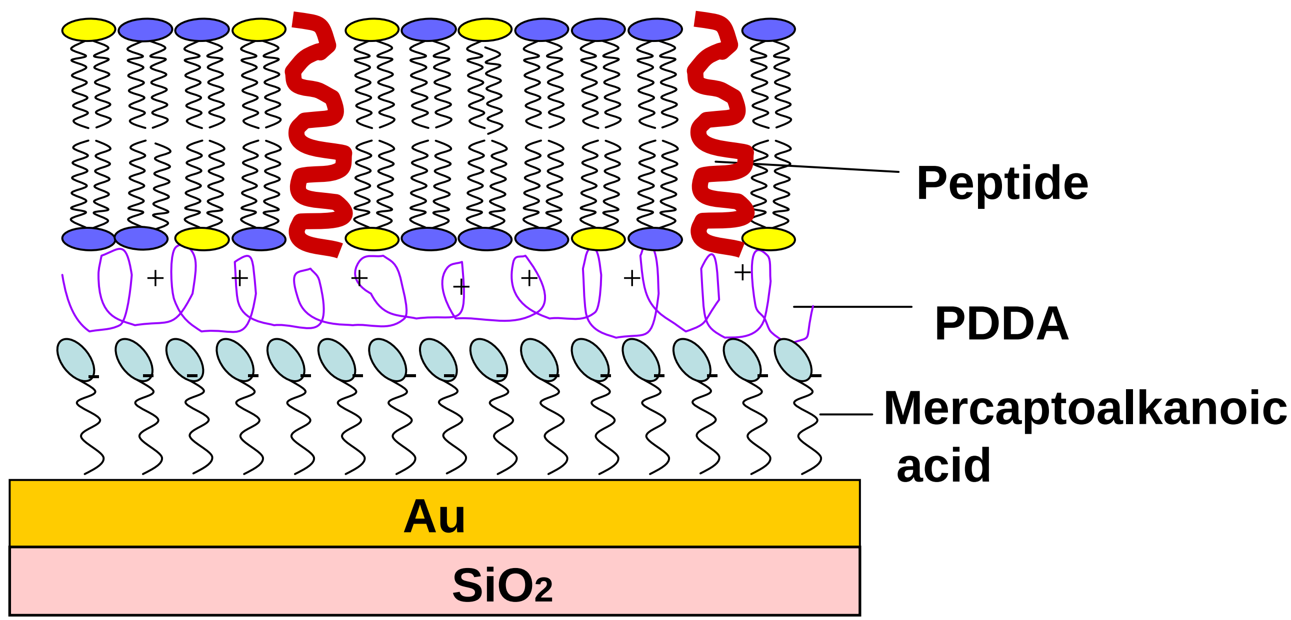
Requirements (to mimic the real cell membrane):
- Stable planar bilayer
- Fluid bilayer (lateral mobility)
- Aqueous environments on both sides of bilayers
- Preserve biological activity for molecules inserted
- Sensing or screening proteins/peptides/ligands

Zwitterionic Lipid POPC

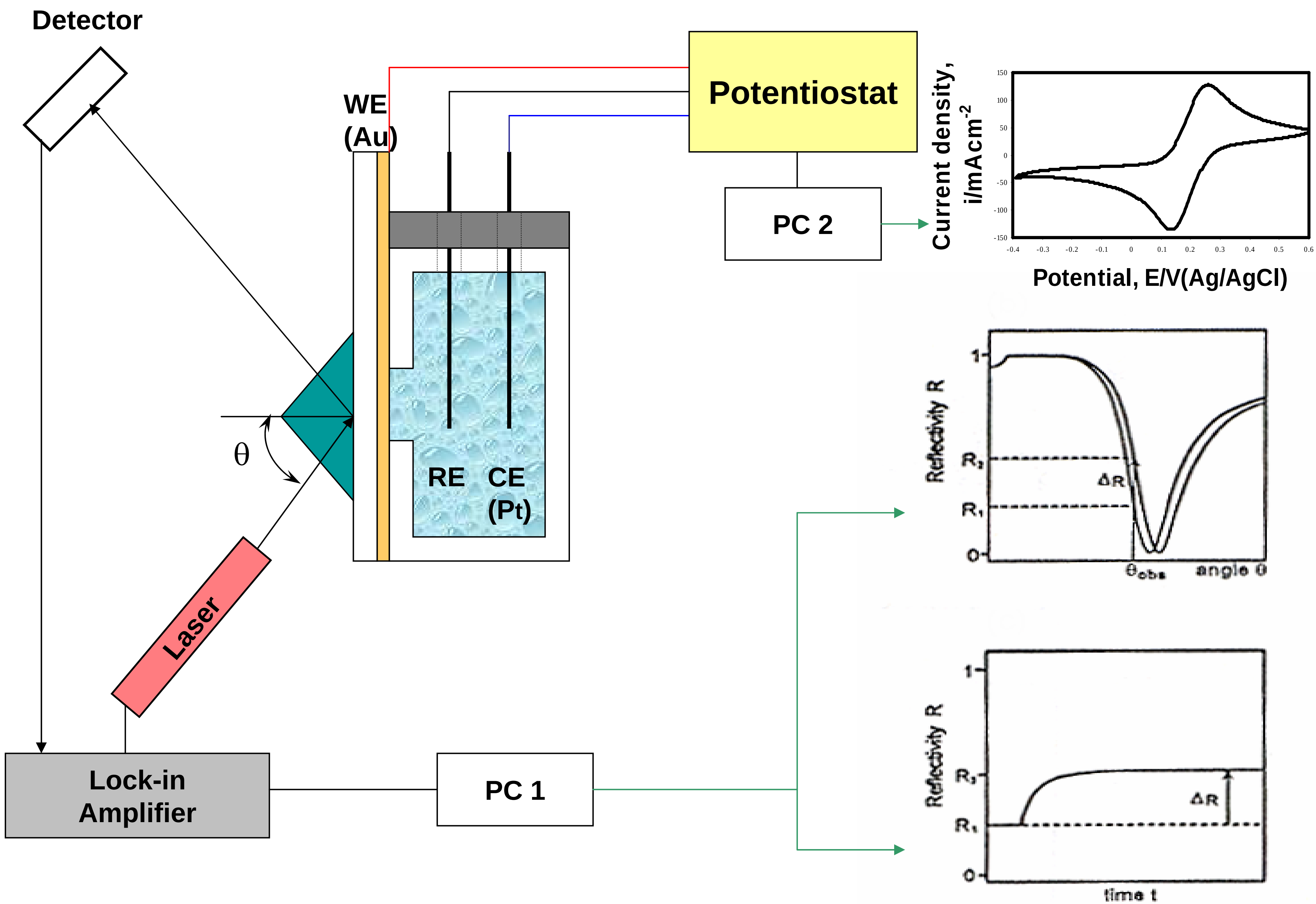


Negatively Charged Lipid SOPS

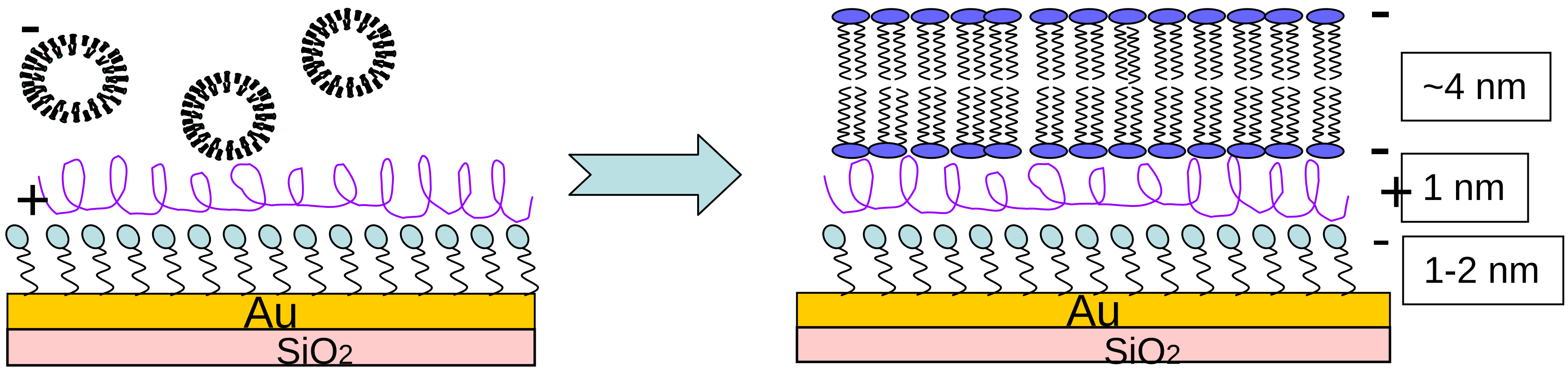


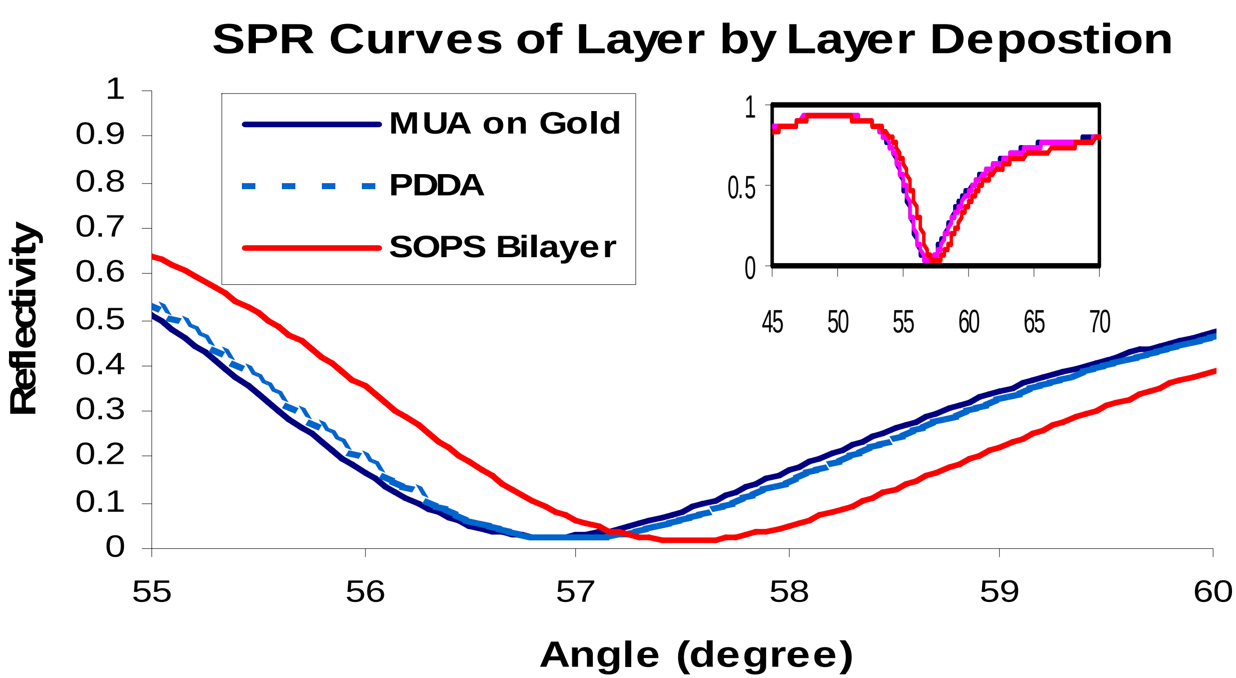


Experimental set-up: SPR with CV



SPR: layer by layer deposition





Lateral mobility of lipid bilayers

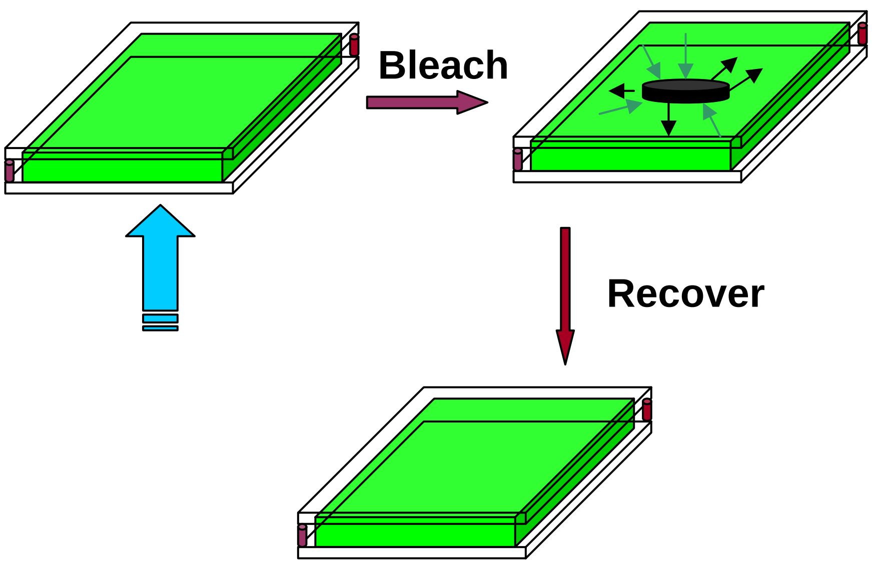
Pure SOPS and SOPS/POPC Mixtures on PDDA

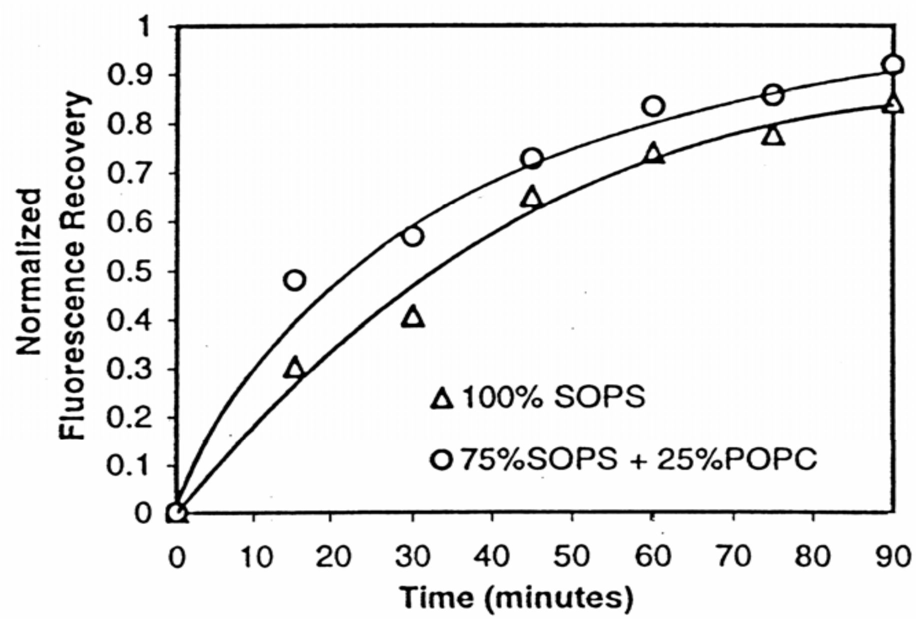
Diffusion Coefficient: D (cm^2/s)=$0.224\omega^2/t_{1/2}$

ω (cm): radius of bleached spot; $t_{1/2}$ (s): half time of recovery

- 100% SOPS: D~$1x10^{-9}$ cm^2/s
- 75% SOPS + 25% POPC: D~$2x10^{-9}$ cm^2/s
- Natural membranes: D~10^{-8} cm^2/s; Immobile membranes: D~10^{-11} cm^2/s

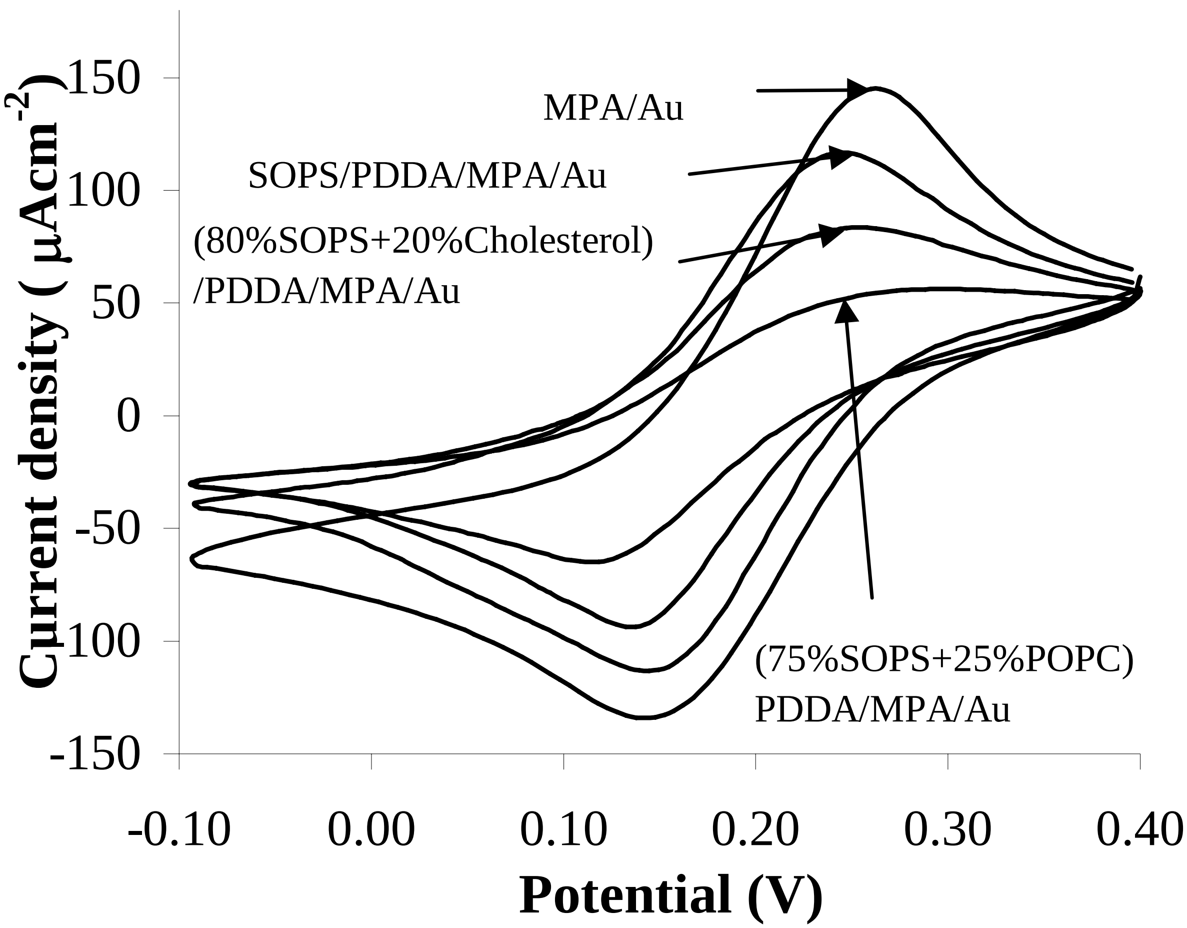
Fluorescence Recovery After Photobleaching (FRAP)



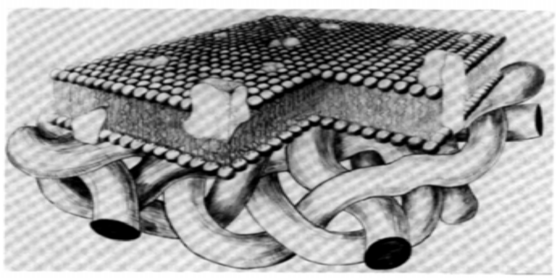


Cyclic voltammetry on lipid bilayers

Zhang, Stroeve et al., Langmuir 2002, JCIS, 2002.



Lipid bilayer / Protegrin on SAM substrate ⟹ biosensor



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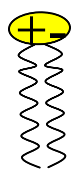
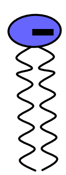
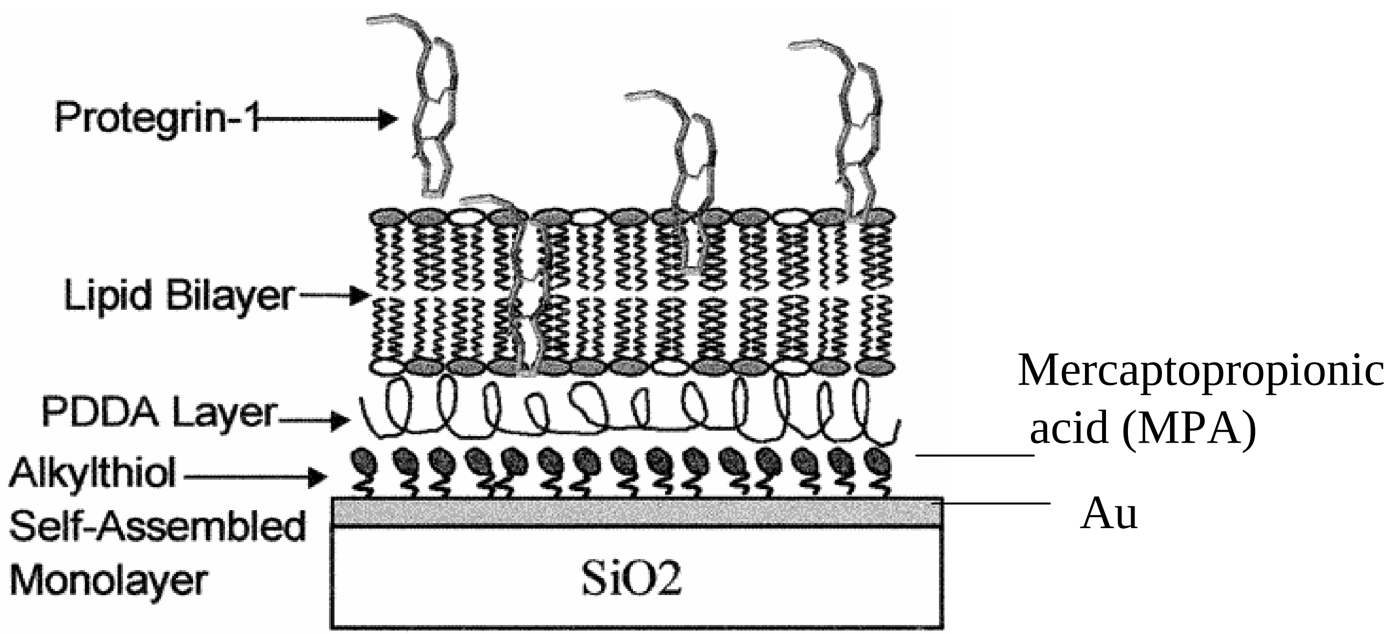


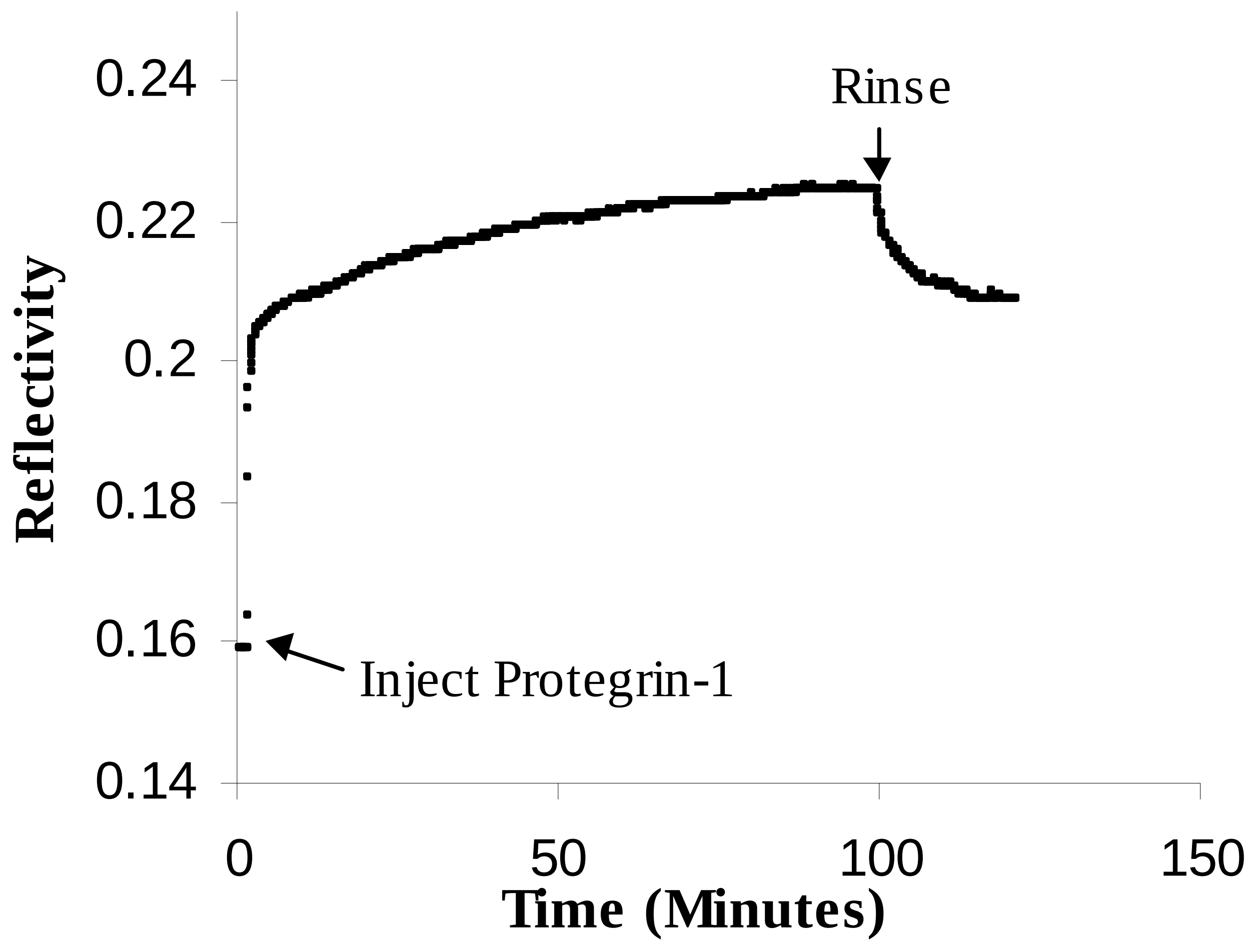
Negatively Charged Lipid SOPS



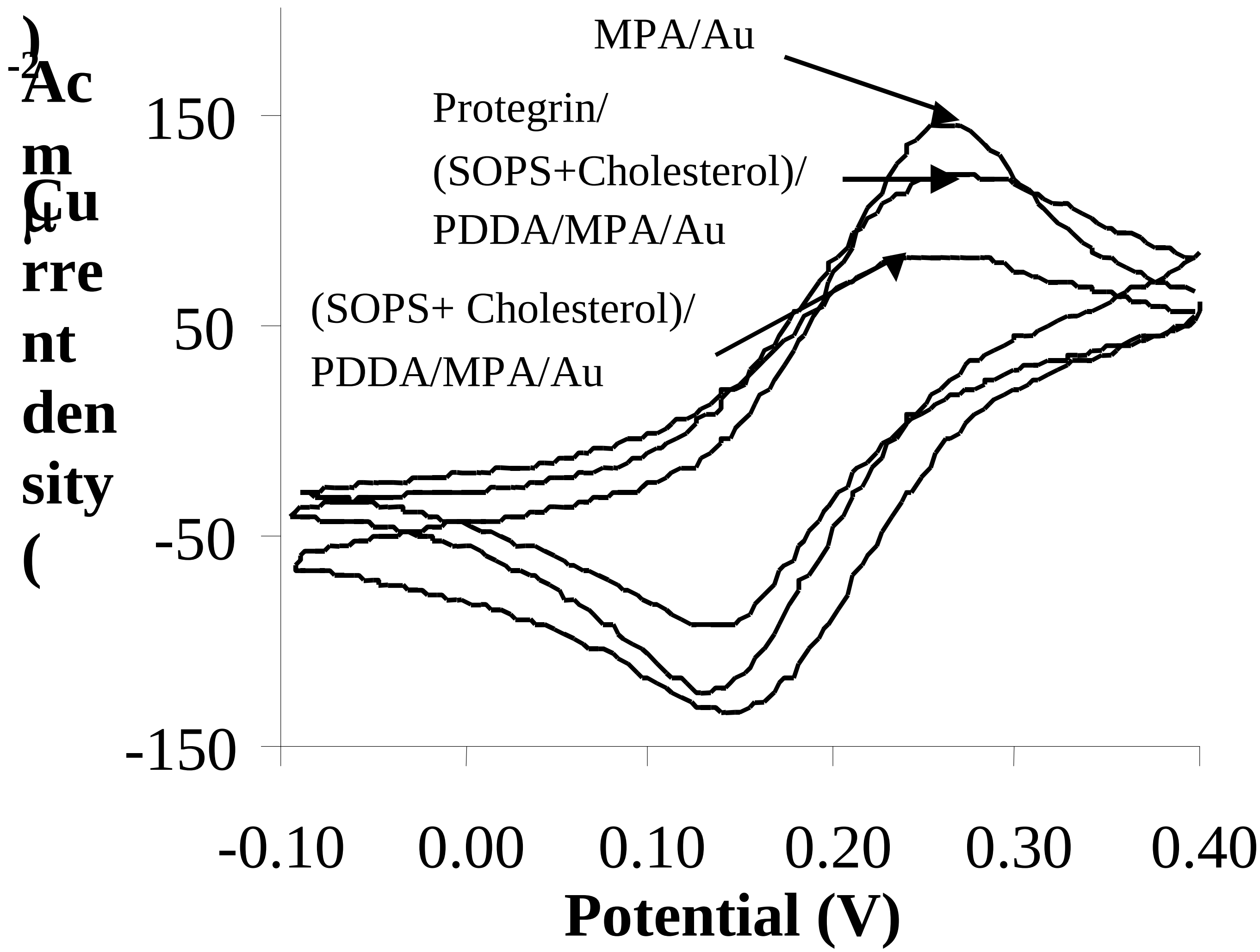


Uptake of protegrin-1 by lipid bilayer

Use of SPR to monitor peptide uptake

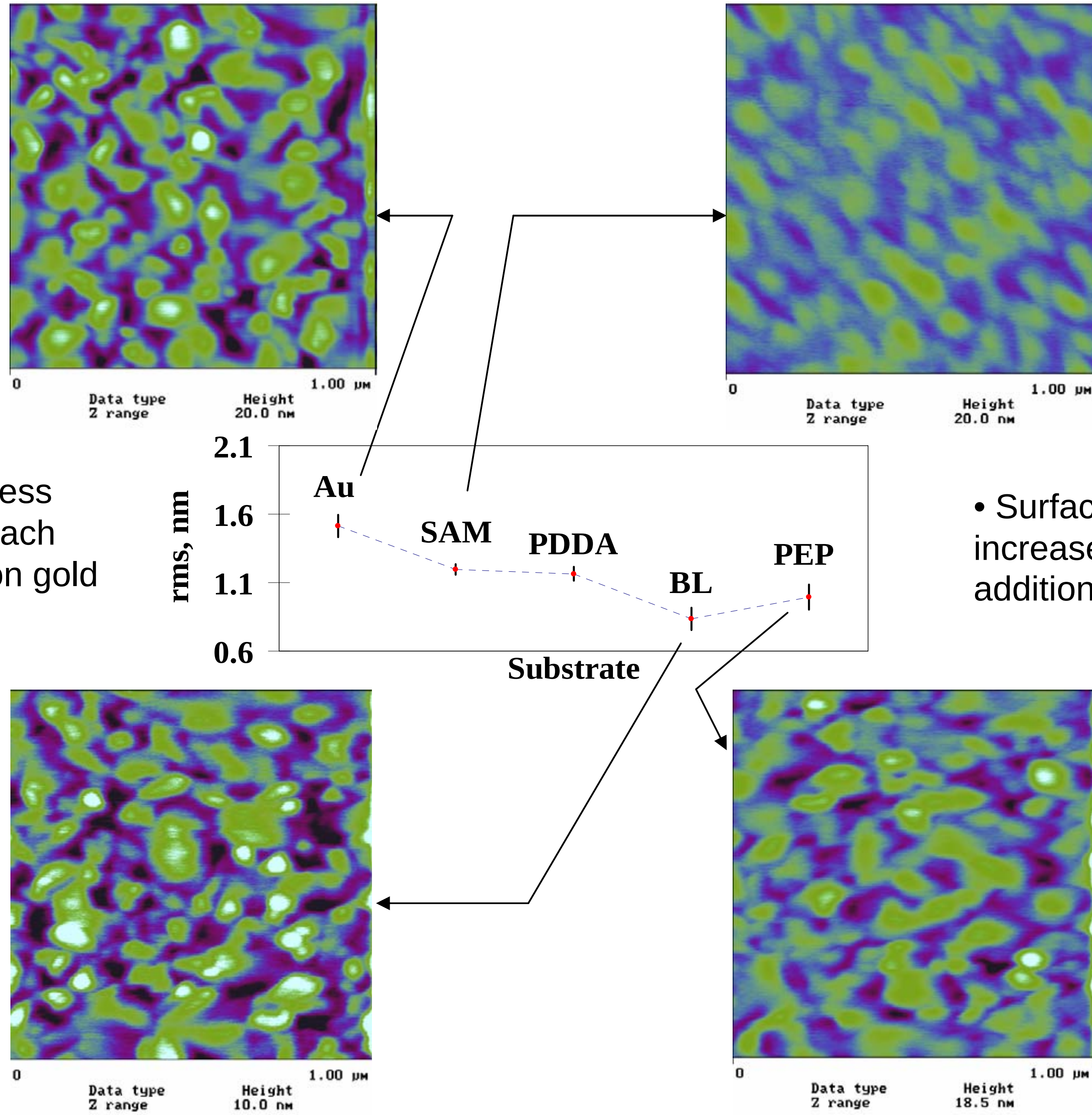


Cyclic voltammetry on lipid bilayers: Protegrin



AFM studies on layer by layer deposition

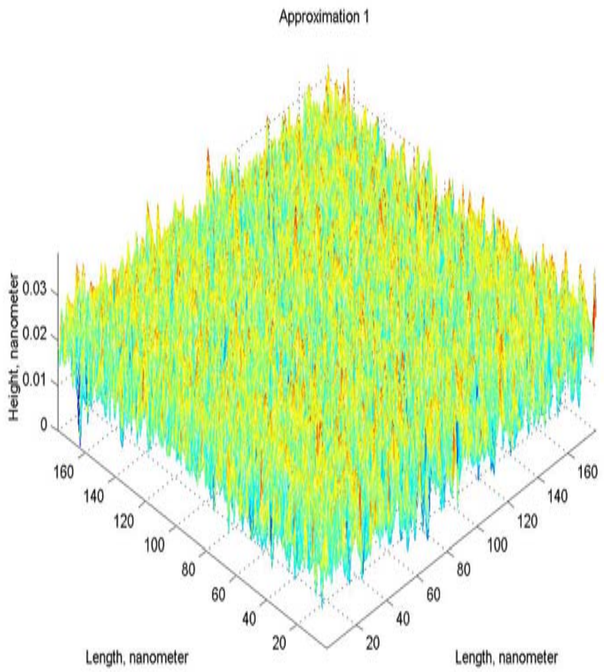
• Surface roughness decreases with each layer deposited on gold surface.

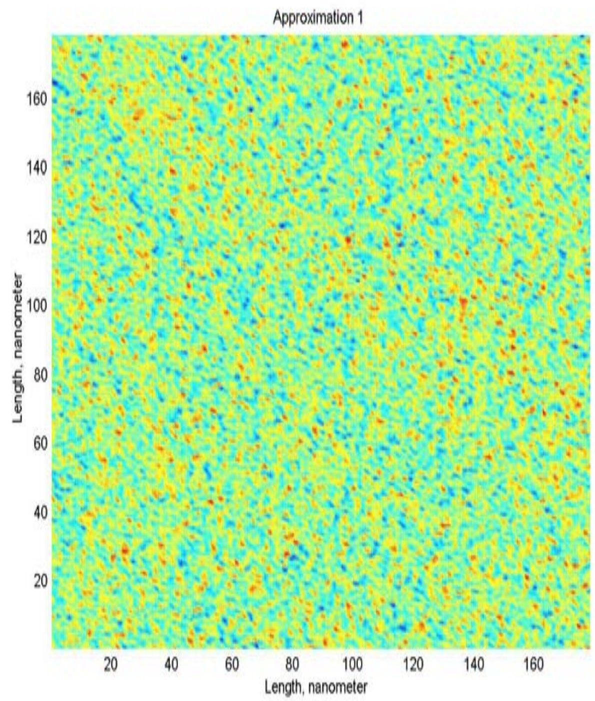


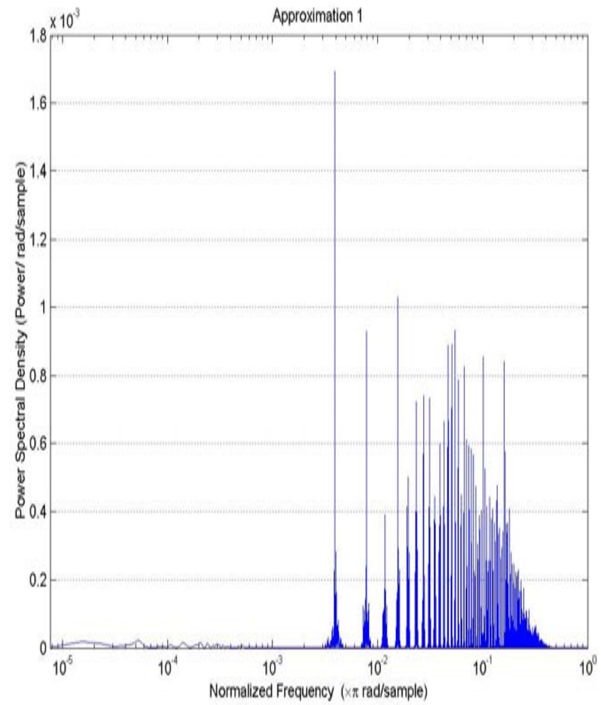
• Surface roughness increases with addition of peptide.

AFM of supported lipid bilayers

Lipid bilayer before uptake of protegrin-1







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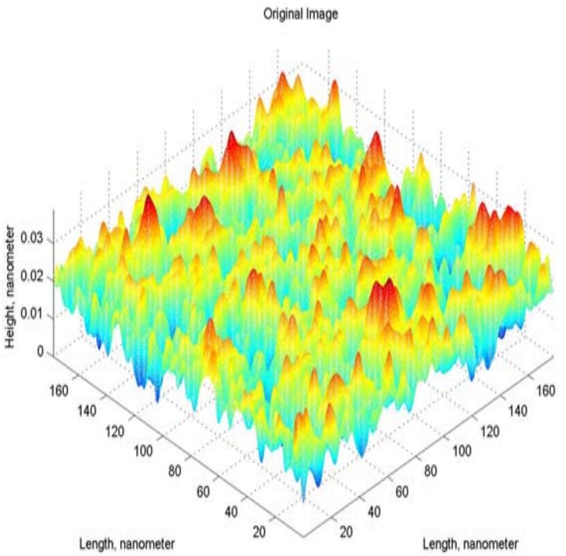
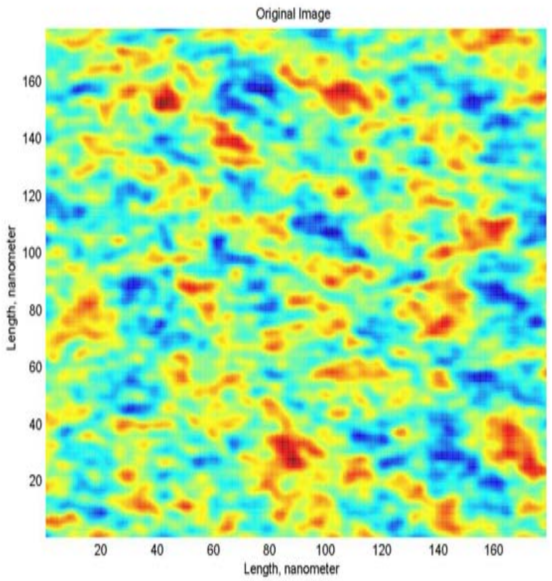
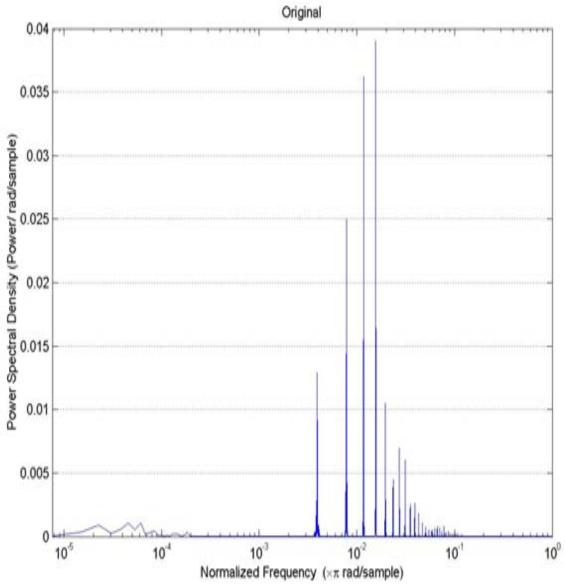
AFM of supported lipid bilayers

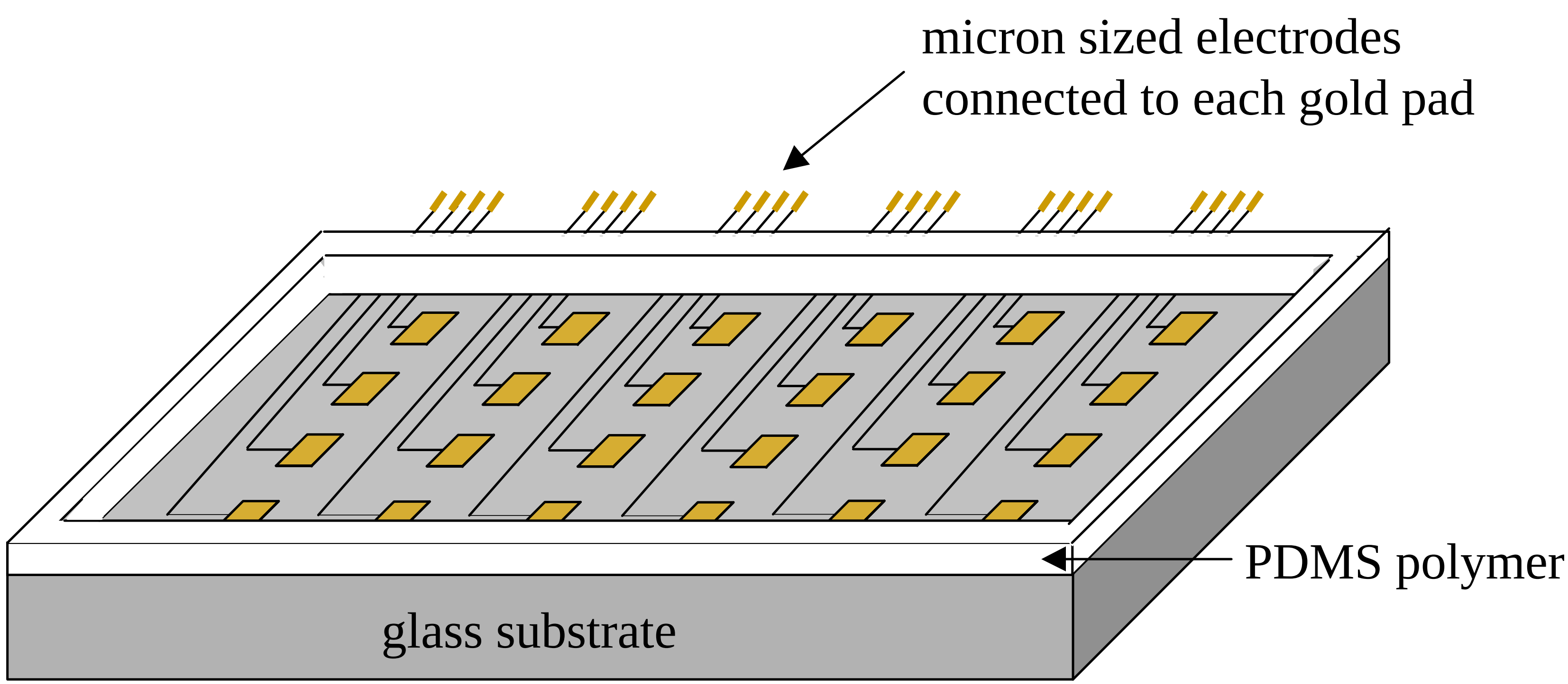
AFM of supported lipid bilayer <u>after</u> uptake of of protegrin-1





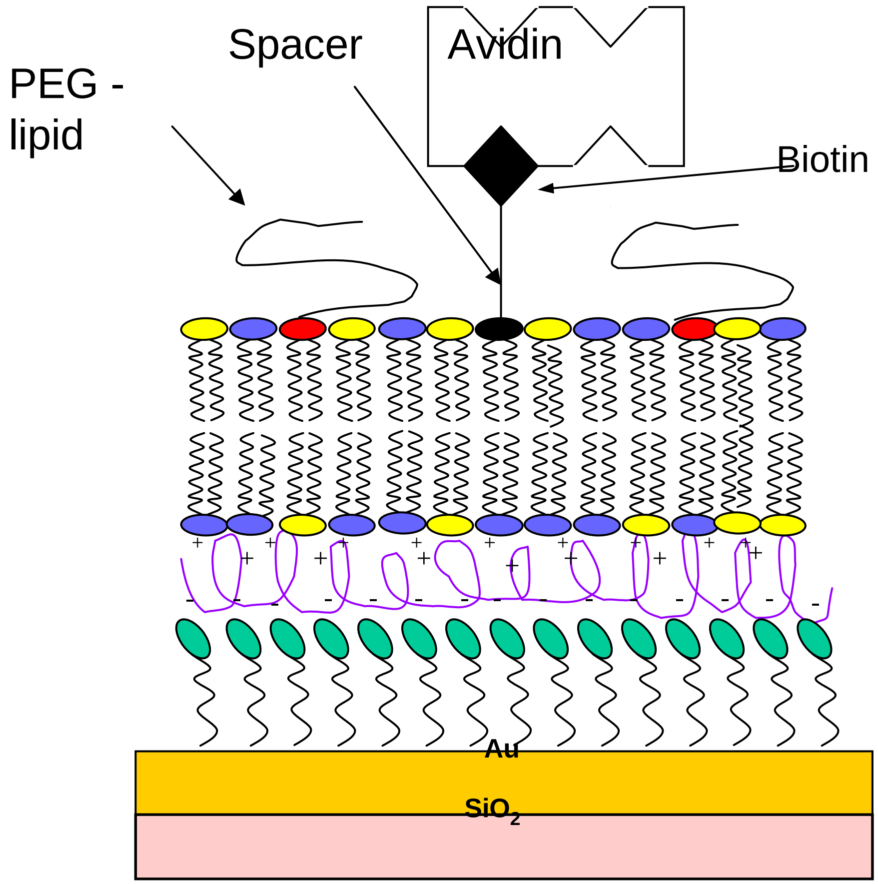


Supported lipid bilayers as micro-array biosensors



Supported lipid bilayer as biosensor for avidin

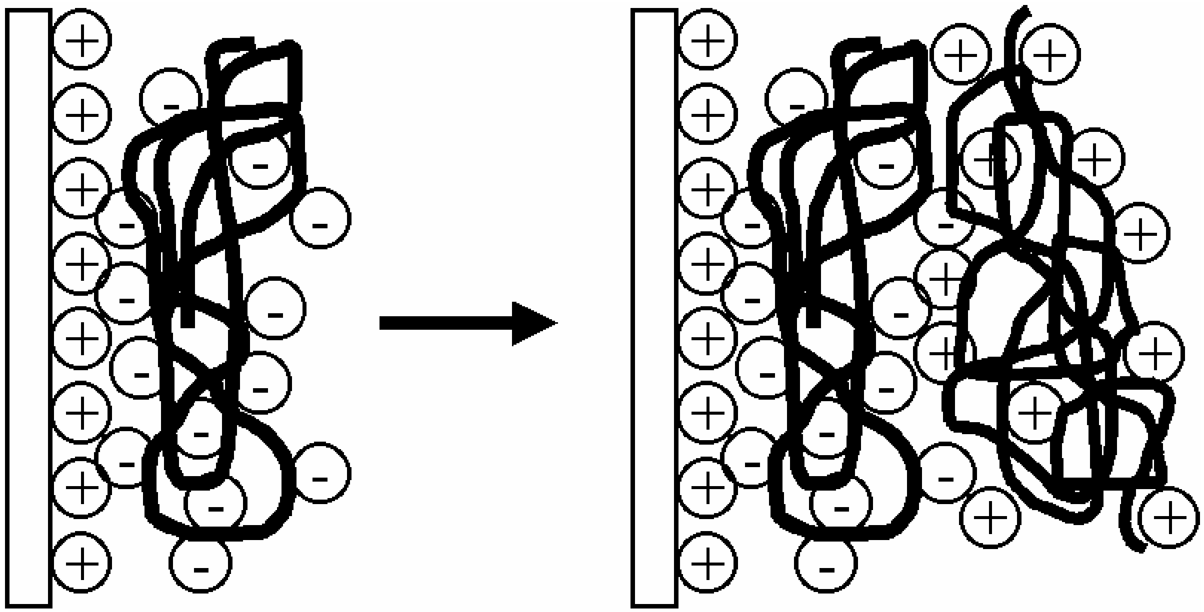
Detector for protein avidin. Also shown is use of PEG-lipid at about 10 mole % , to prevent disrupting species from reaching the bilayer.

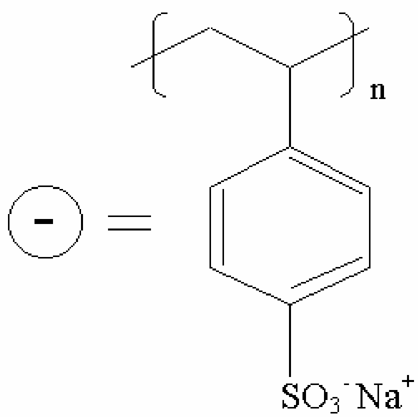


Self-assembly of molecular structures

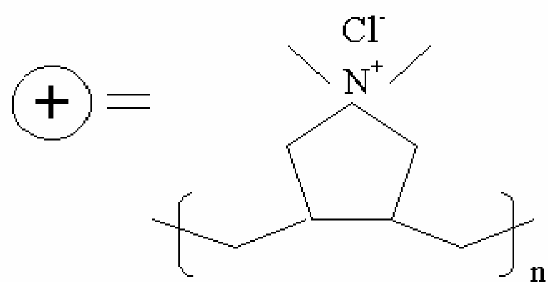
- Self-assembled monolayers (SAMs)
- Self-assembly of macromolecular structures on surfaces
- ➔ Layer-by-layer deposition of polyions
- Stamping
- Self-assembly of diblock polymers
- Self-assembly of macromolecules

Layer-by-layer deposition of polyions





Polystyrene sulfonate,
(PSS)



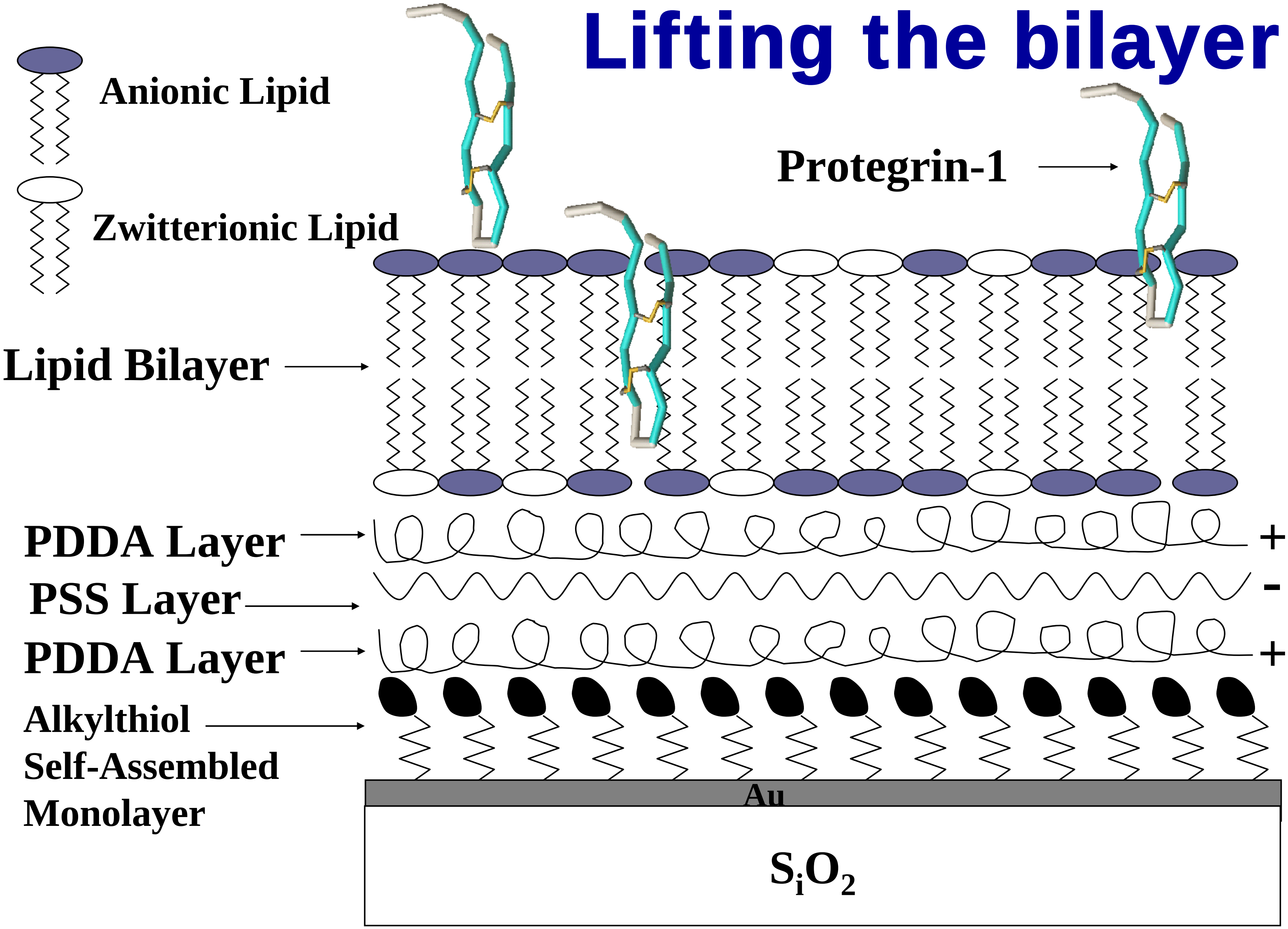
Polydiallydimethlyammonium chloride,
(PDDA)

Layer-by-layer deposition of polyions

Applications

- Lifting supported bilayers
- Biosensors
- Permselective membranes
- Catalytic films
- Coatings

Lifting the bilayer

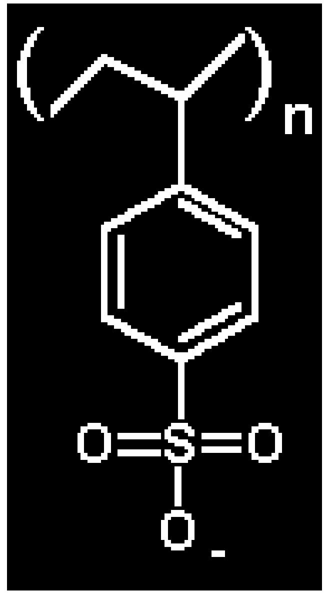


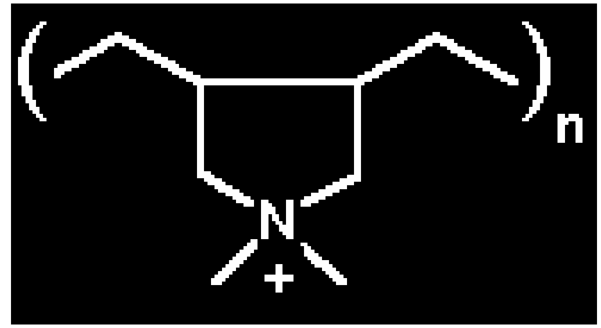
C. Ma, Stroeve et al., Coll. & Surf. B, 2003

Layer-by-layer deposition on SWCNT

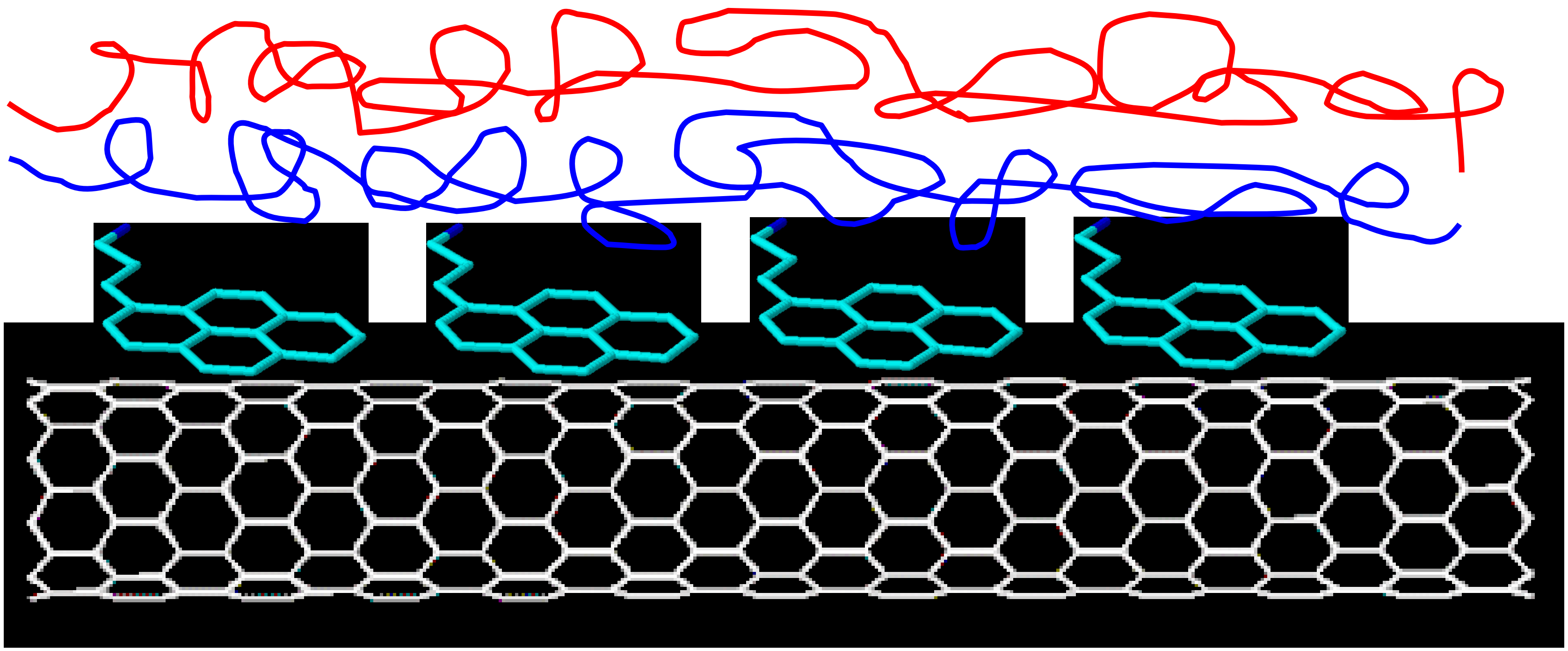
Arthyukhin et al., Langmuir, 2004

Polystyrenesulfonate



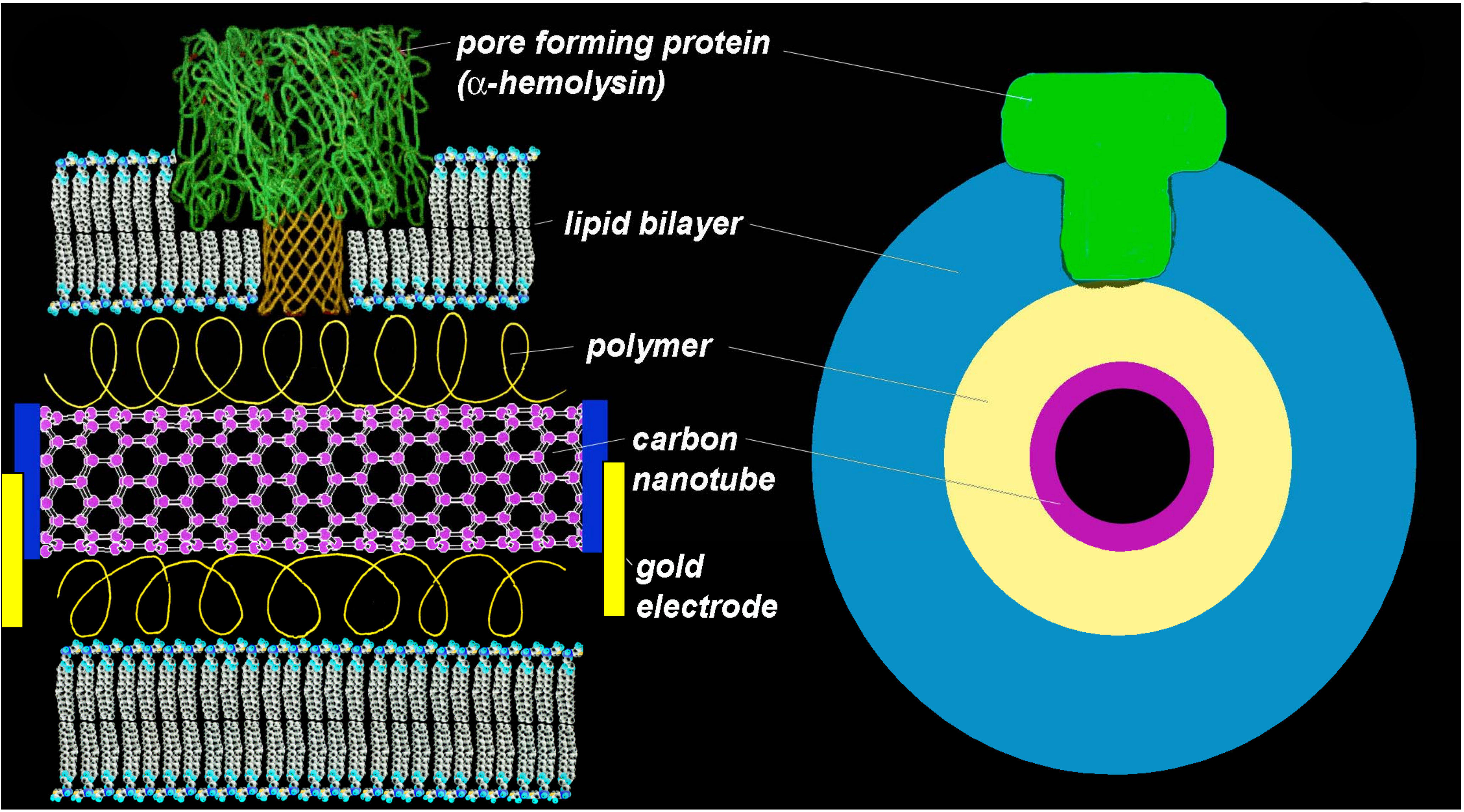


PDDA

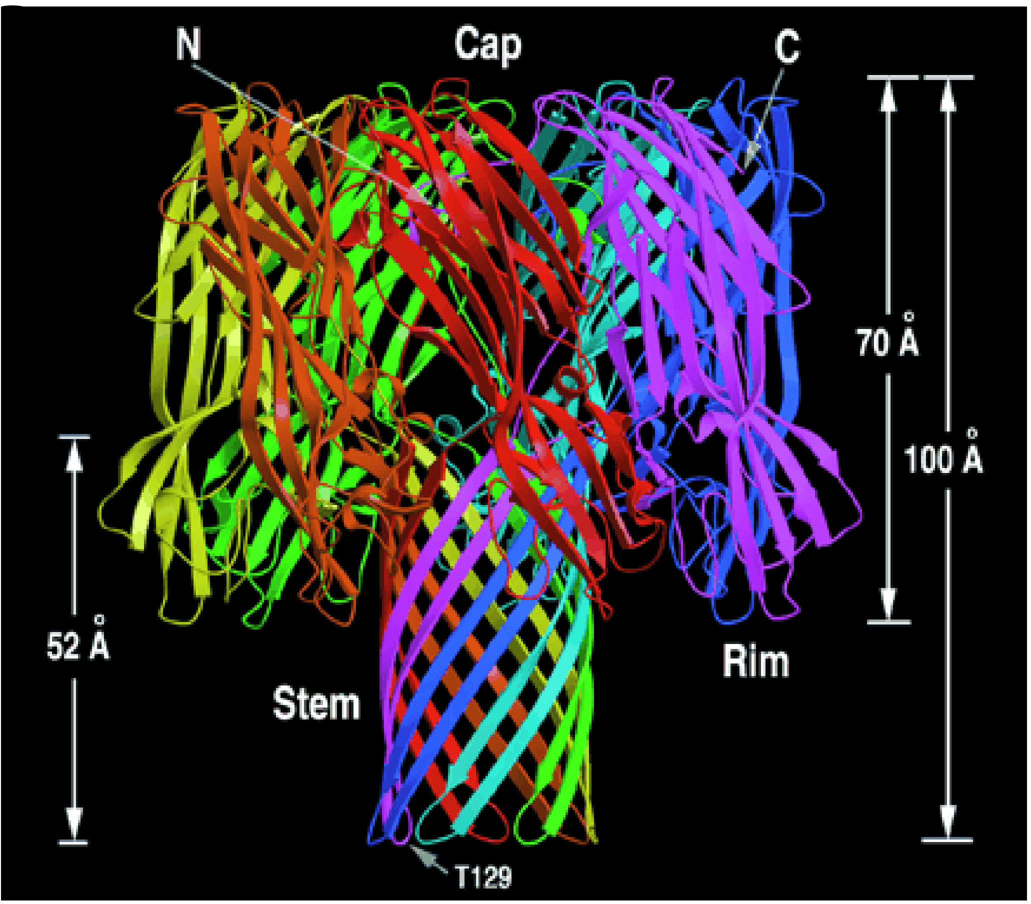


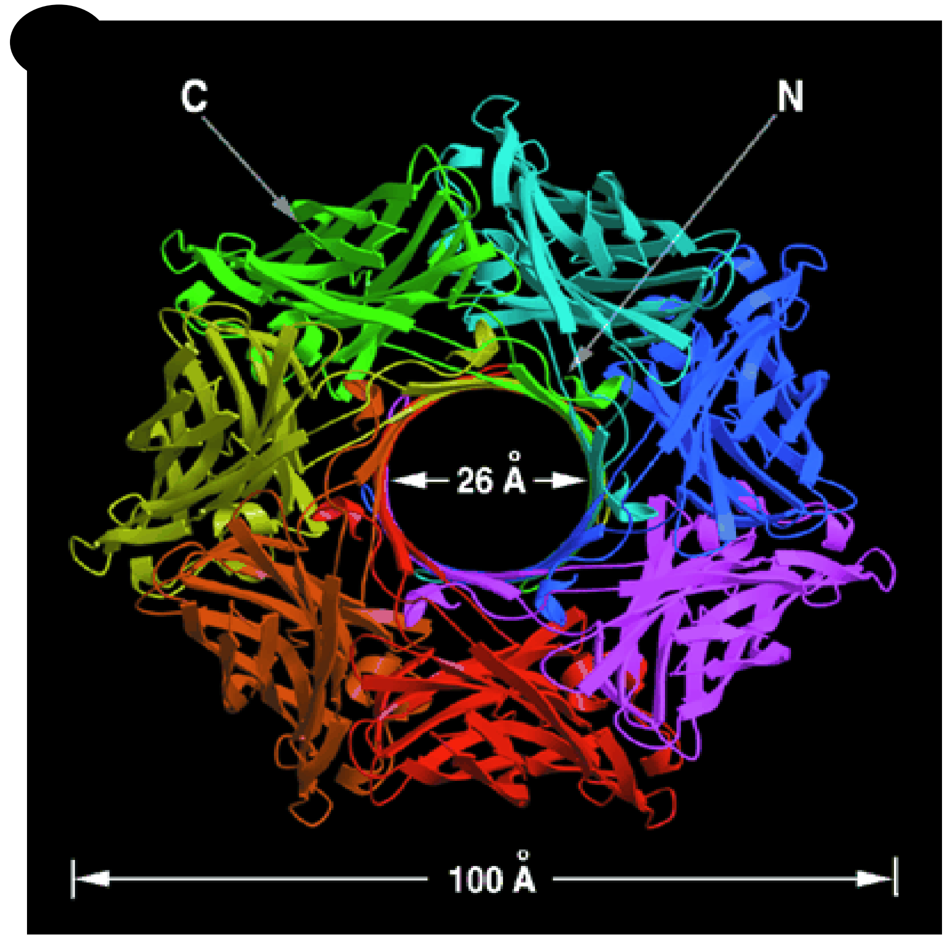
Carbon nanotube sensor

Arthuykhin, Stroeve et al., 2004



α-Hemolysin





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- Self-assembled monolayers (SAMs)
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- Self-assembly of diblock polymers
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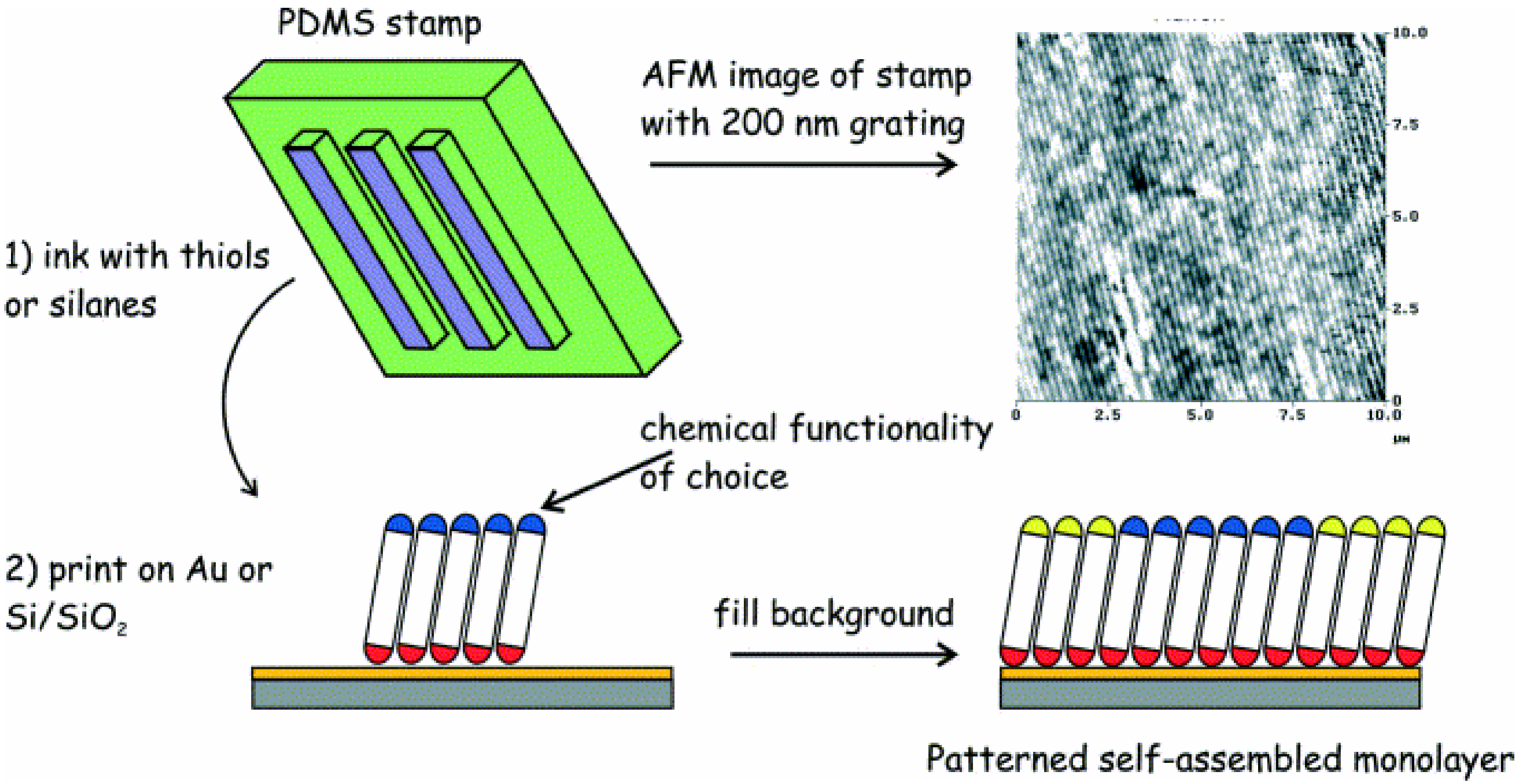
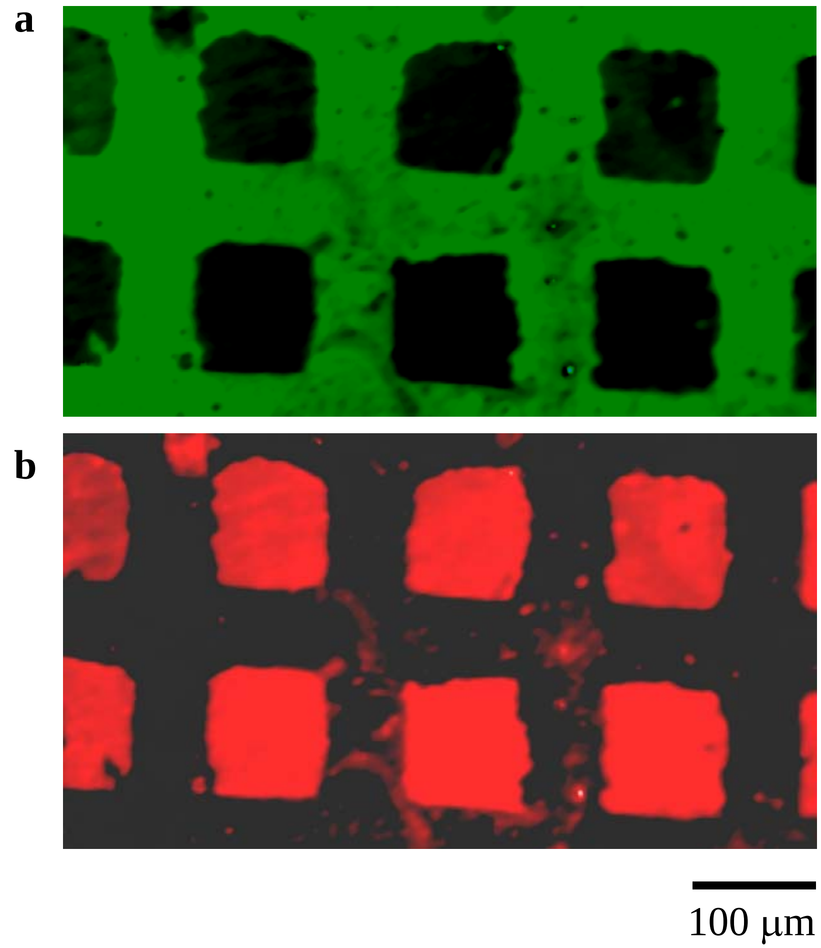
Stamping (microcontact printing)

Li and Huck, Curr. Op. Solid State and Mat. Science, 2002



Patterning of supported lipid bilayers

Use of stamping or microcontact printing. **Srinivasan, Stroeve et al., Langmuir 2001**



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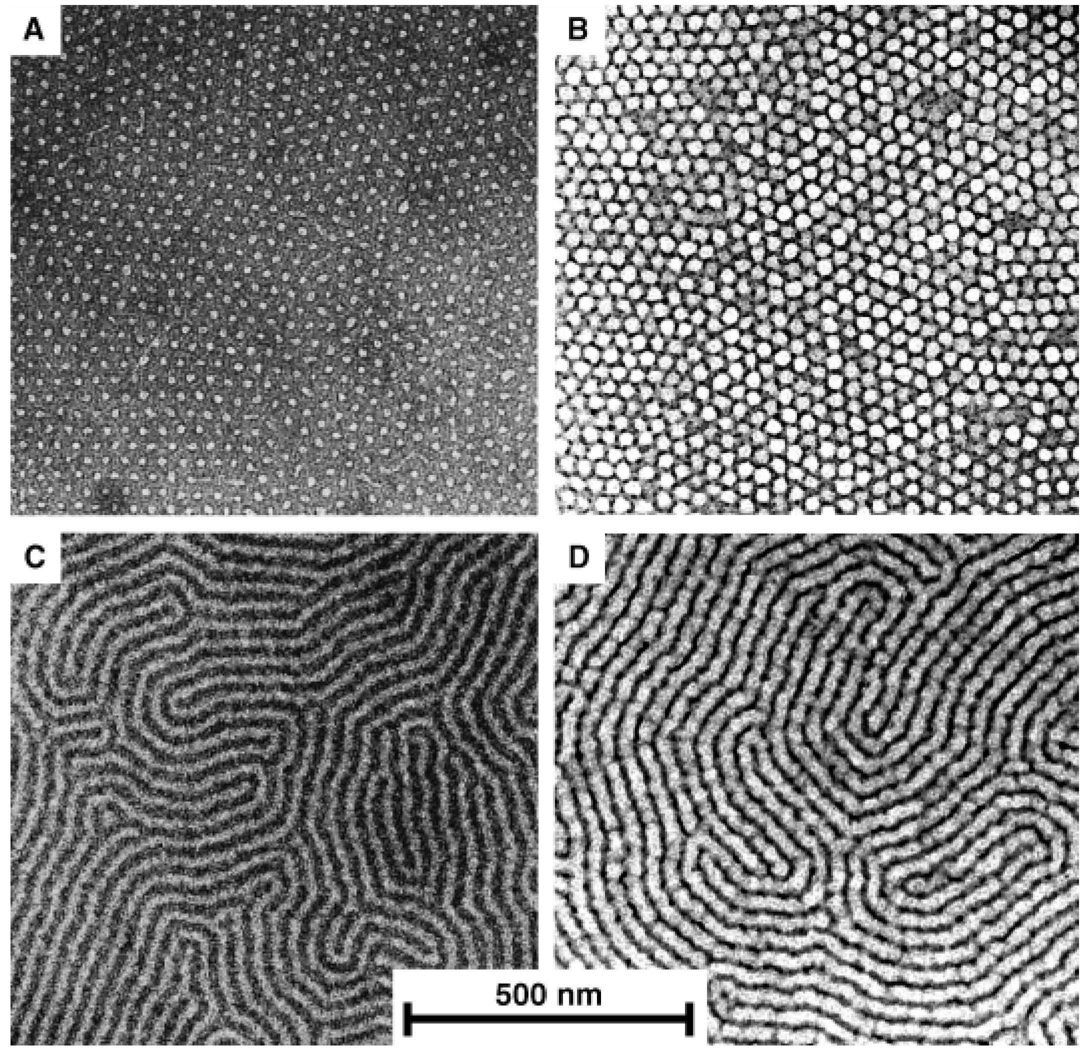
Self-assembly of diblock polymers



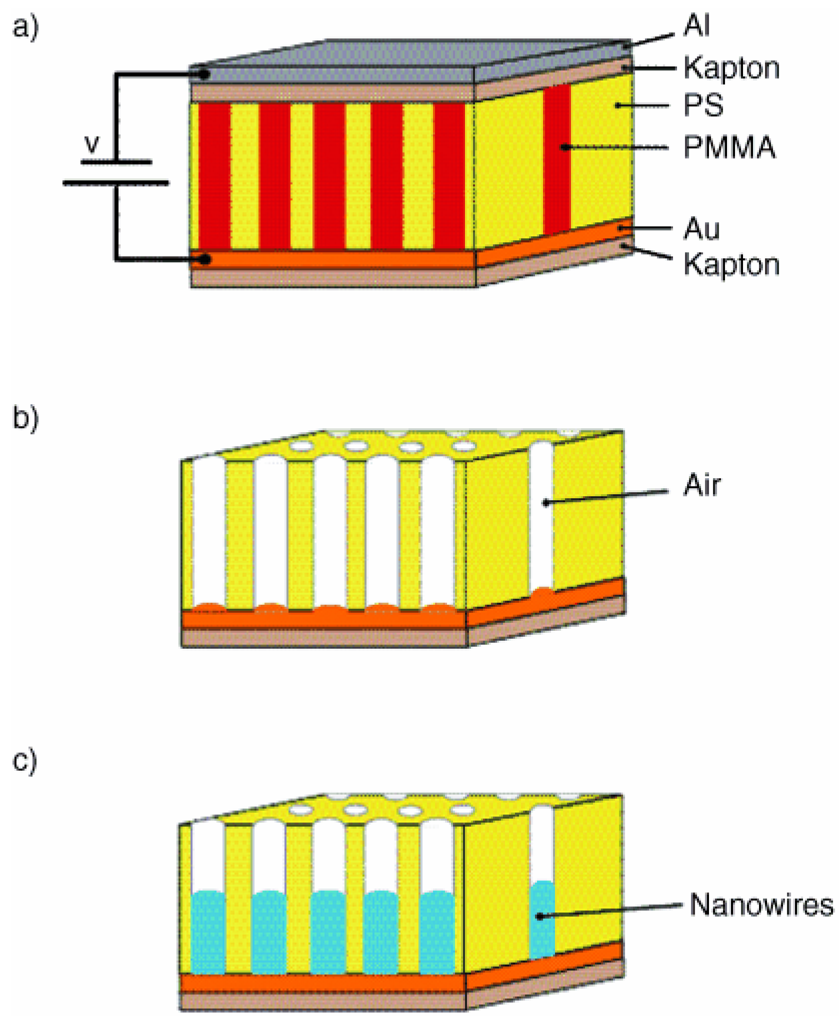
TEM micrographs of polystyrene-polybutadiene diblock copolymer film masks (a,c) and lithographically patterned silicon nitride (b,d).

(C. Harrison, Science)

Nanowire-arrays

Nanowire-array formation. a) An asymmetric diblock copolymer is annealed above the glass transition temperature of the copolymer between two electrodes under an applied electric field. b) After removal of the minor component, a nanoporous film is formed. c) Nanowires formed by electrodeposition in 20 nm pores.

(from M.T. Tuominen, Science)



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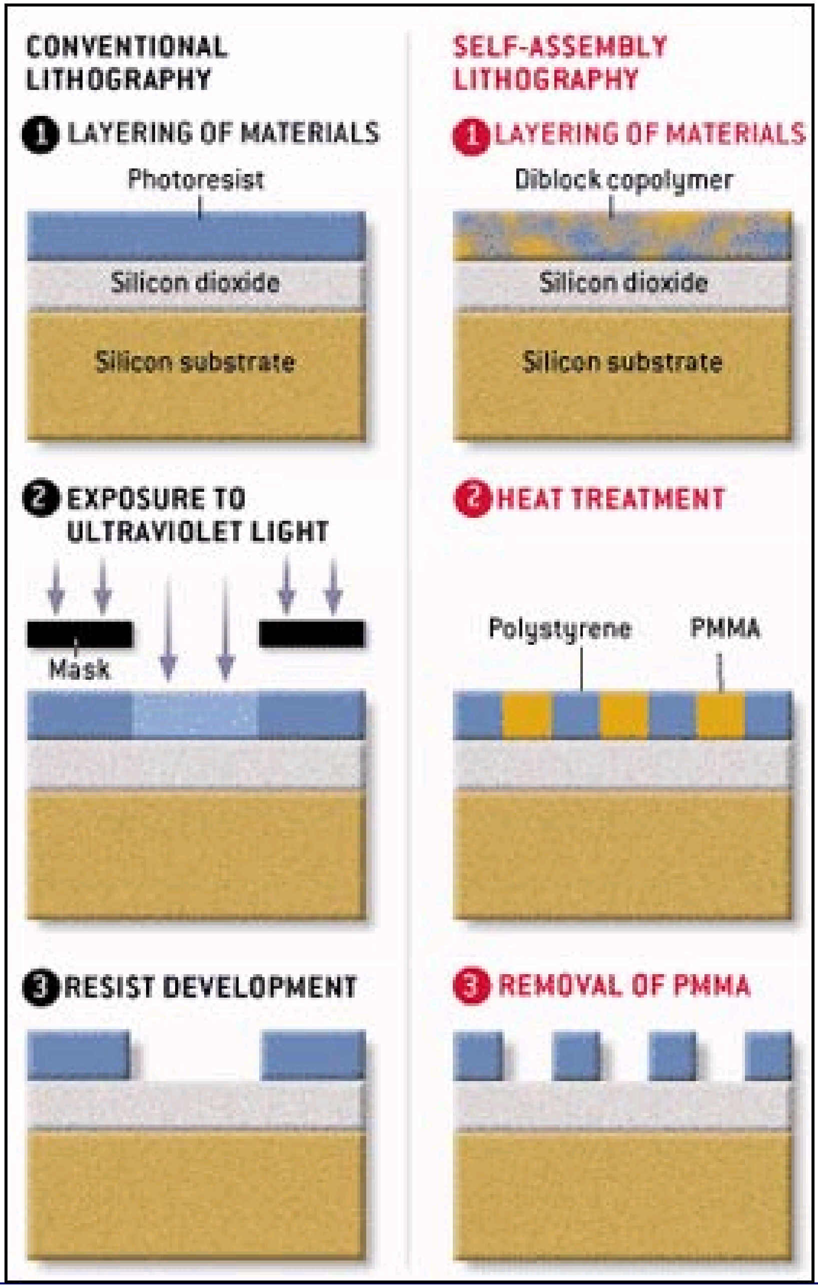
Self-assembly lithography (IBM)

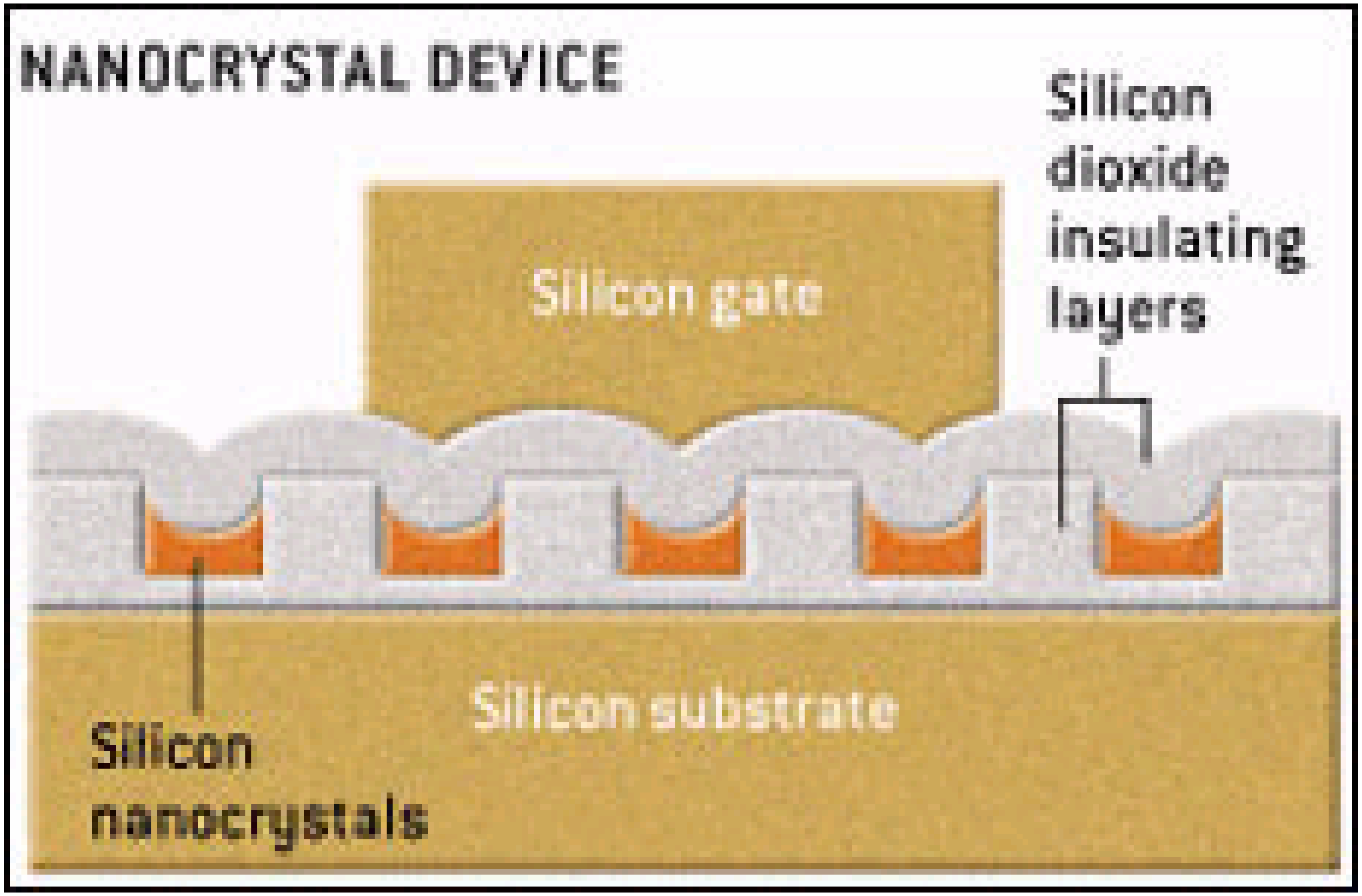
Self-assembly patterning occurs when a diblock copolymer is heated, thereby separating the two polymers in the material into defined areas before the PMMA is etched away. The template of cylindrical holes is transferred into the silicon dioxide before the holes are filled with nanocrystalline silicon used to store data (20 nm size).



IBM Flash memory device

FLASH MEMORY: A layer of self-assembled silicon nanocrystals is inserted into an otherwise standard device as part of a novel IBM manufacturing process.

Image: SAMUEL VELASCO



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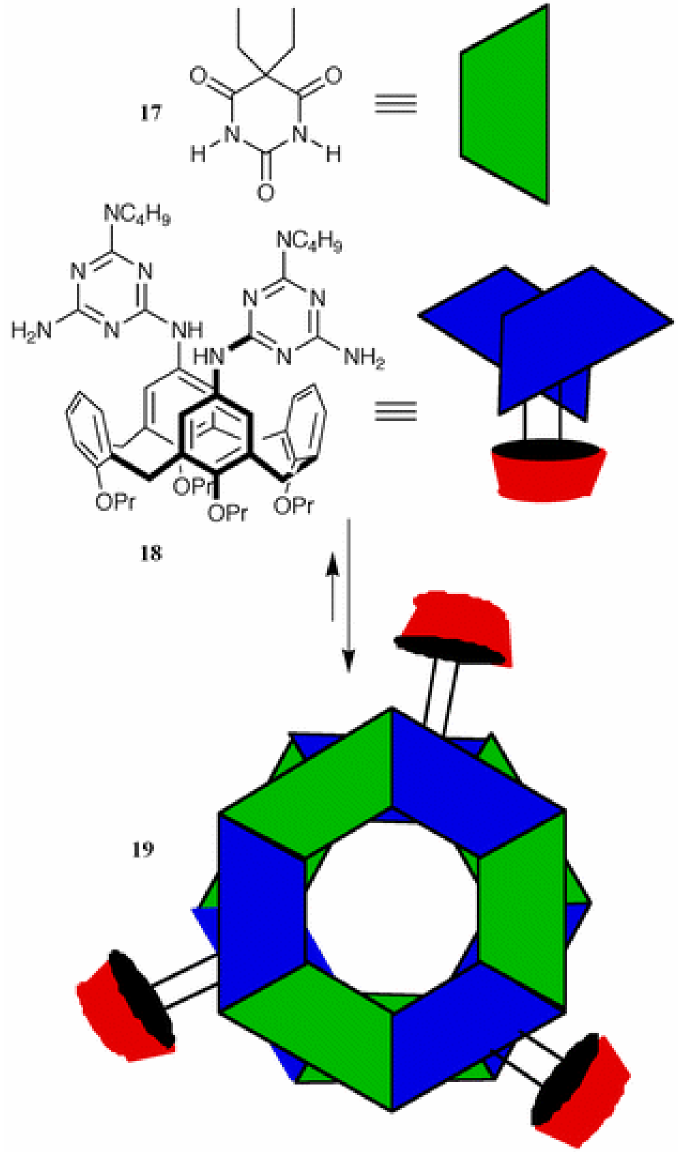
Self-assembly of macromolecules

Self-assembly of a double rosette superstructure 19 through the interaction, mediated by hydrogen bonds, of barbiturate 17 with melamine derivative 18

R.N. Reinhoudt, U of Twente, Angew. Chemie, 1996



Self-assembly of molecular structures

CLOSING COMMENTS:

•Molecular assemblies can be build on a variety of substrates.
•Combination of bottom up and top down techniques can lead to patterned features.
•Research on self-assembling structures on surfaces has stimulated the development of new products.