Self Assembly of Optical Structures in Space

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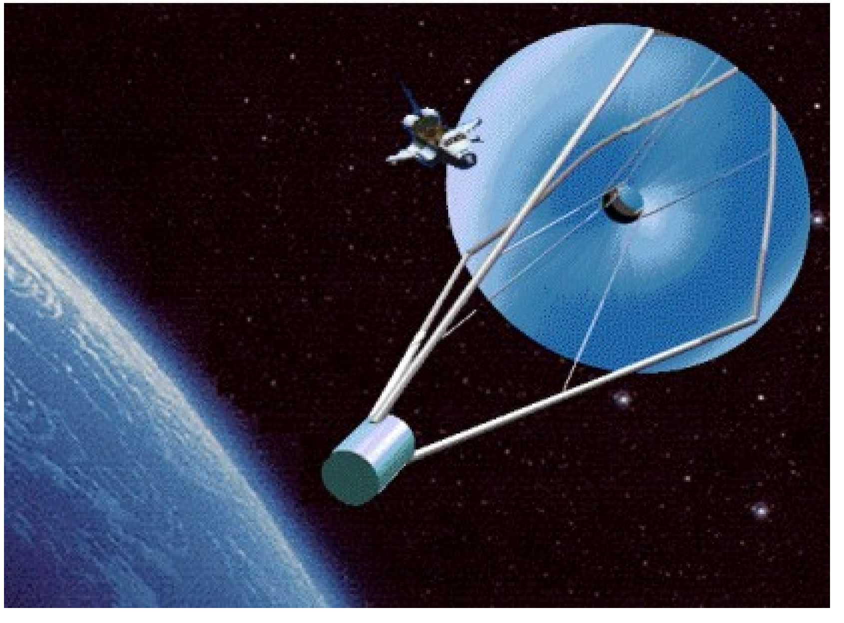
ABSTRACT: The concept is to apply self-assembly processes to the manufacture of telescope mirror components in space or on the surface of planetary bodies such as the Moon or Mars.

Motivation: Study the most distant objects in the universe.
Find inhabitable planets orbiting other stars.

Launching a 6 m telescope (the James Webb Space Telescope) is impractical.

Can we “grow” a structure in space, or on the moon that could be made into a telescope mirror?

Can “self-assembly” chemistry and biology be useful for this purpose?



What is self-assembly chemistry and biology?

All living organisms are self-assembled!

But there are many other examples as well, including

(1) Polymers

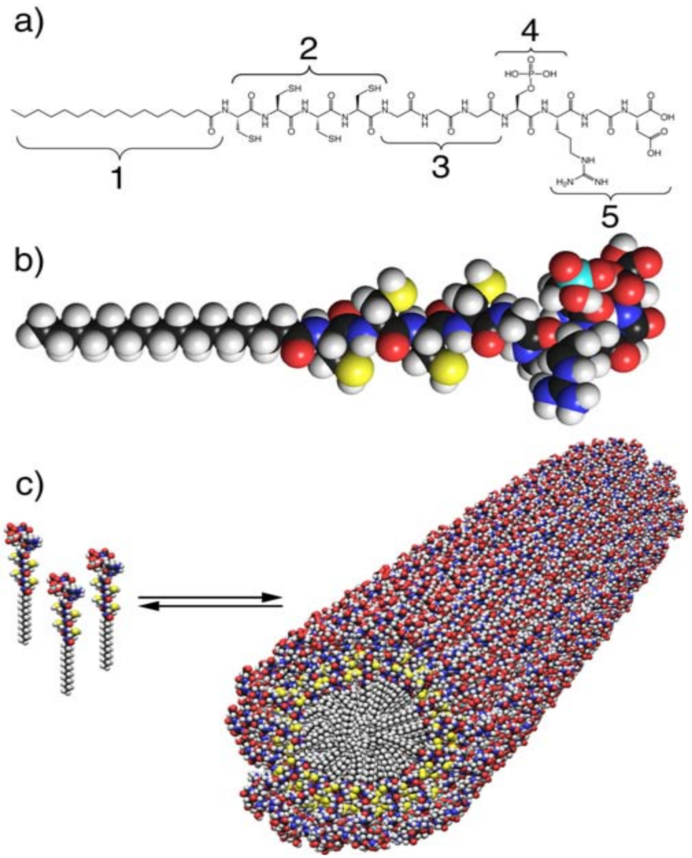
(2) Peptide Amphiphiles

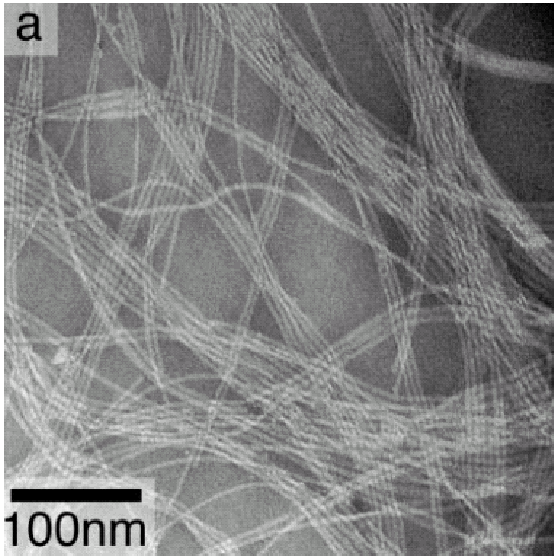
(3) Metal particles on surface of fungus

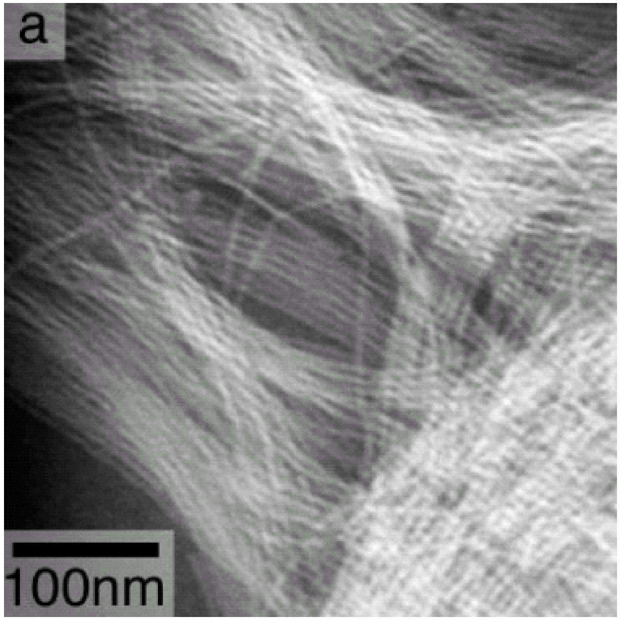
Polyurethane synthesis in a beaker: Synthesis produces a lot of gas (CO_2) that makes the resulting polymer mass porous. As a result, the growing polymer foam expands out of the beaker and overflows the surroundings.

OH–R–OH + OCN–R'–NCO ==> [–CO–NH–R'-NH–CO–O–R–O–]$_n$

Cylindrical micelle structures from peptide amphiphiles



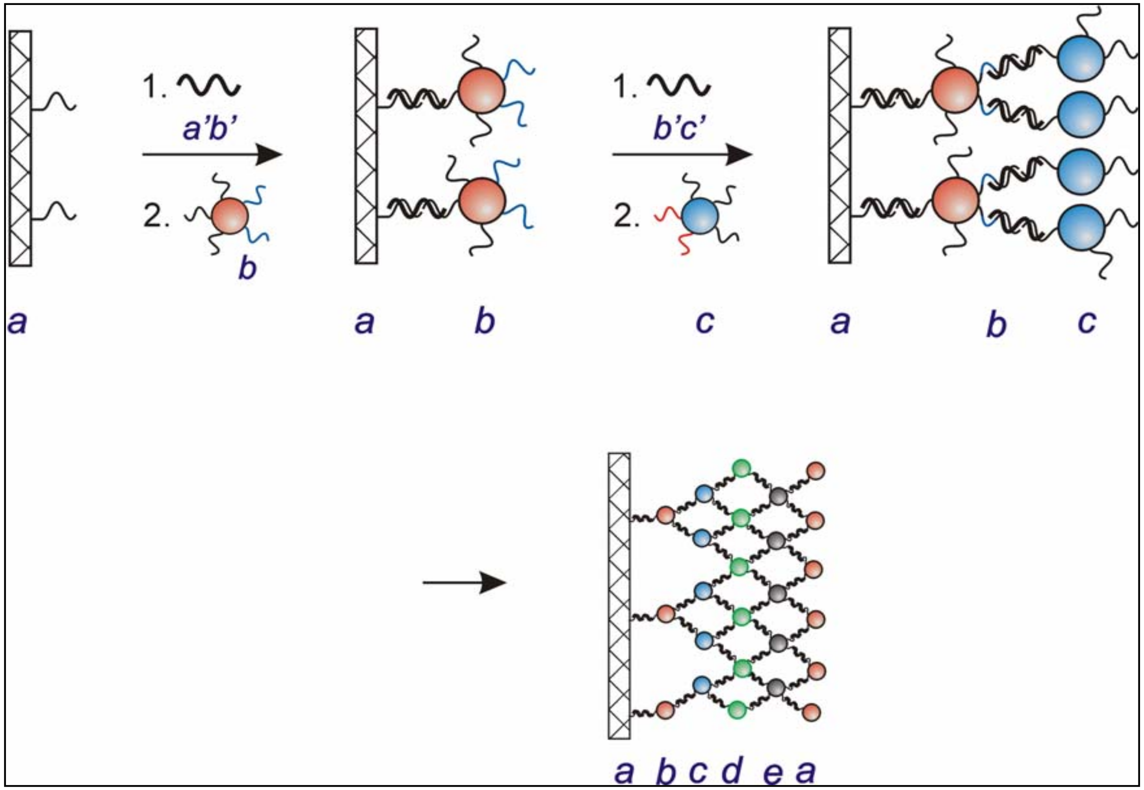




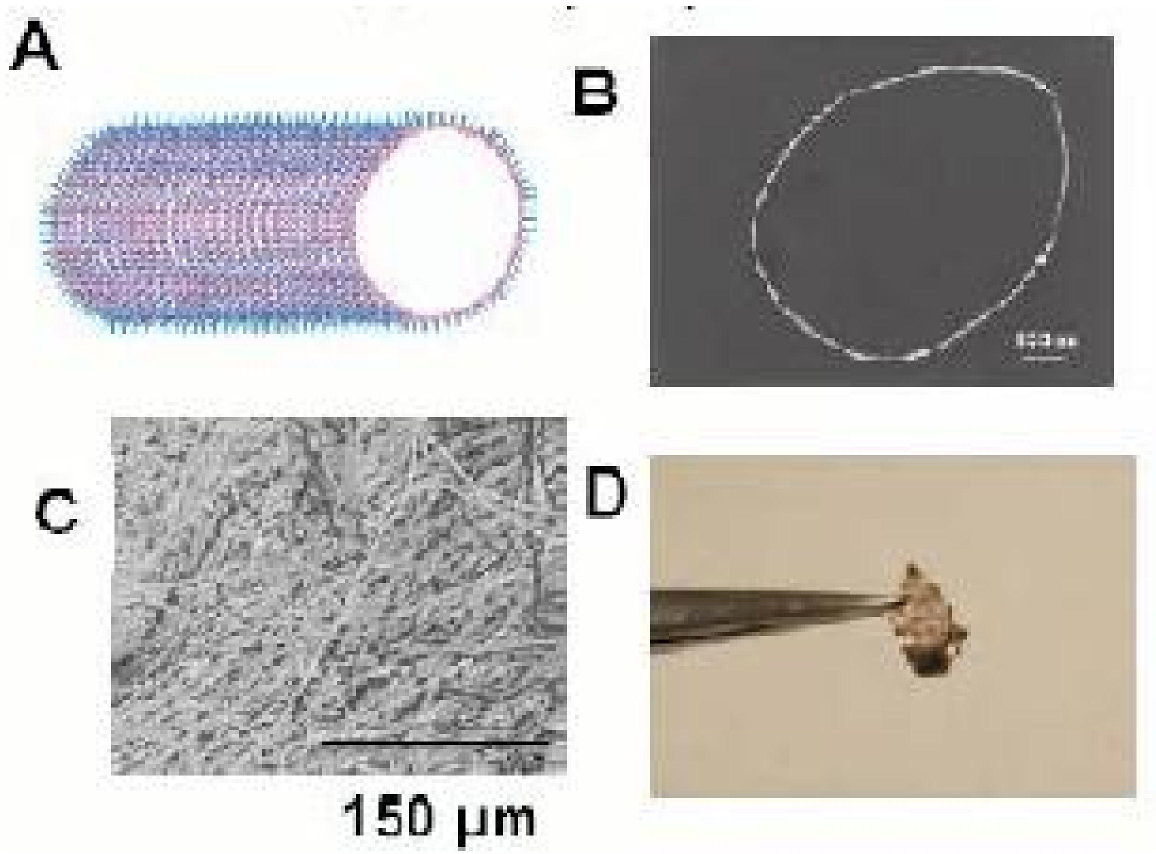
From J.D. Hartgerink, E. Beniash, and S.I. Stupp, Science, **294**, 1605 (2001).

Using DNA as the "glue" to build nanoparticle assemblies

(Chad Mirkin, Northwestern)



Self assembled metal/plant structures at the micron scale



A: cylindrical fungus structure; B TEM of a cross section of "A"; C sheet made for air drying fungus tubes; D, macroscopic picture of "C", a tweezers hold the ~ 1 mm x 1 mm gold foil

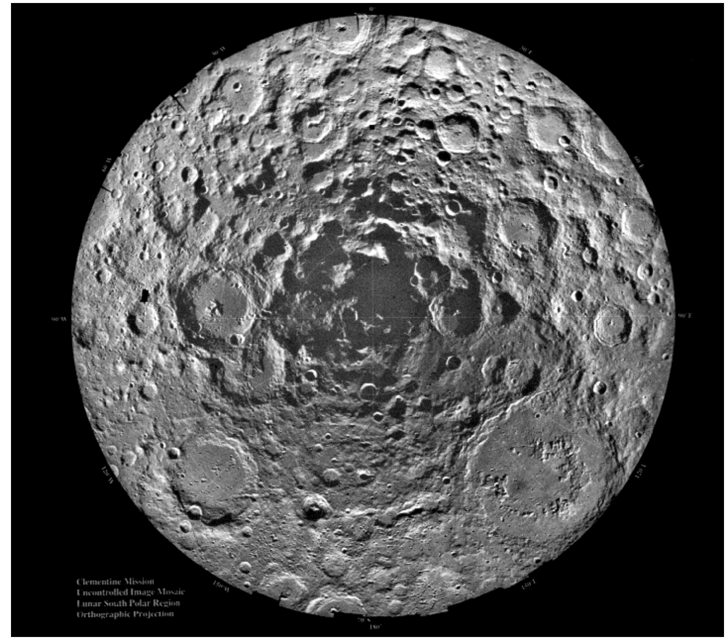
General Considerations for NAIC Project:

Self Assembly in Orbit versus on the
 Moon (Mars)
 Are water/minerals available for free?

Biological versus nonbiological
 self assembly

Conditions for self assembly
 (temperature, pressure, system complexity)

Structures for building
 Assemble from smaller components, or try to grow the whole structure in place
 Make inside space station, or in a balloon



South Pole of Moon

Outline of Project

(1)Growing biological structures

(2)Growing nonbiological structures (polymers, inorganics)

(3)Coating surfaces, especially biological surfaces, with shiny metallic coatings.

Group: Mary Unger (biologist), Encai Hao (chemist)
Mel Ulmer (astronomer), George Schatz (chemist)

Growing plants with controlled structures in space

Past work: there have been many shuttle experiments which have demonstrated that green plants can be grown in space. These are grown hydroponically, so soil isn't needed, however water and minerals are, as is ventilation (CO_2 provided, O_2 eliminated). Apparently gravity is not important, but the spectrum and direction of light must be controlled carefully.

Directing the growth of plants: As usual the genes determine what happens, but several hormones (small molecules that act as signaling agents) may be used to influence gene expression (and therefore growth): auxins, cytokinins, giberellin and brassinosteroids.

Auxins influence seed germination, cell elongation and expansion.

Cytokinins promote cell division, shoot formation, leaf yellowing.

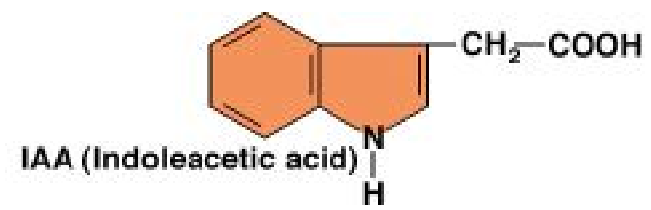
Giberellin promotes cell elongation in conjunction with auxin.

Brassinosteroids induced exaggerated growth.

Auxin was discovered in 1926 although knowledge of its function was know to Darwin.

Auxin determines response of plants to light (auxin migrates to regions of the plant away from a light source). Growth occurs because of loosened cell wall fibers.

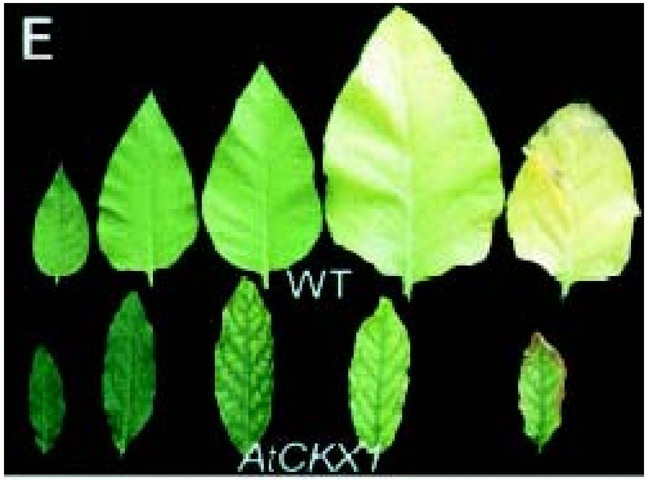
Topical application of auxin leads to root growth, budding and flower initiation.
High concentrations lead to uncontrolled growth and death.



Auxin applied to roots on left and center

Cytokinin was recognized in 1910, but its chemical structure was not determined until 1963.

Cytokinin interacts with auxin to determine the amount of budding versus root growth.

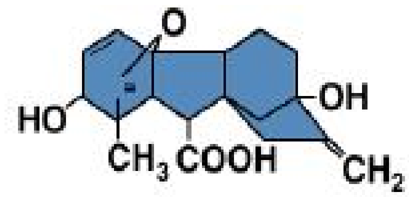


Cytokinin promotes protein synthesis in leaf membranes, delaying the destruction of chlorophyll the produces leaf yellowing.

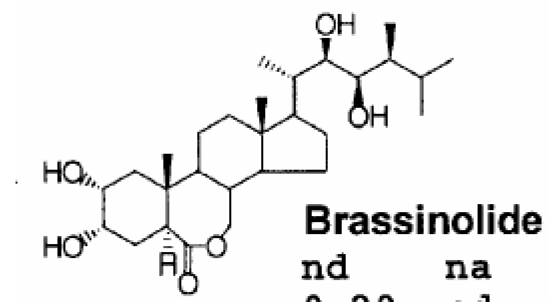
Comparison of tobacco leaves at various states of growth:
Top: wild type Bottom: with overexpression of cytokinin

Giberellin promotes cell elongation.

Application of giberellin to rice leads to longer stalks, but eventually the plant collapses as it can’t support its own weight.



Normal and foolish rice



Brassinosteroids

Overexpression of the gene for producing Brassinolide leads to uniformly larger plants (picture shows results for tobacco). [S. Choe et al, The Plant Journal 26, 573 (2001)]

Absence of brassinosteroid leads to dwarf plants.

Growing nonbiological surfaces:

Here we borrow from what is already well known from industrial polymer applications. The product a polymer with a well-defined shape, there a three commonly used processes:

Injection molding – inject into a mold (used for making toys)

Extrusion molding – force polymer through an opening (used for making fibers)

Blow molding – inflate polymer against walls of mold (used for soda bottles)

Normally all of these methods have heavy equipment needs, and creating a mold with be a big problem for space applications.

Is it possible to create large light molds in space using balloon structures? Apparently this has not been studied.

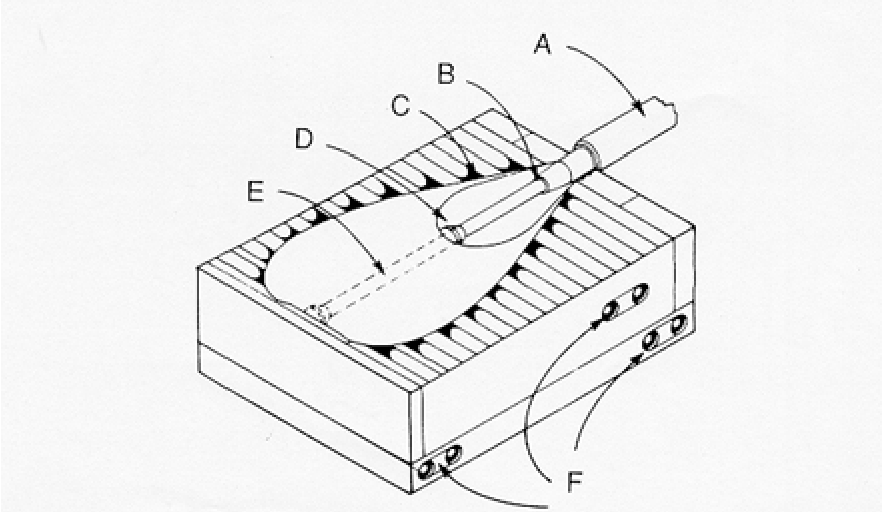
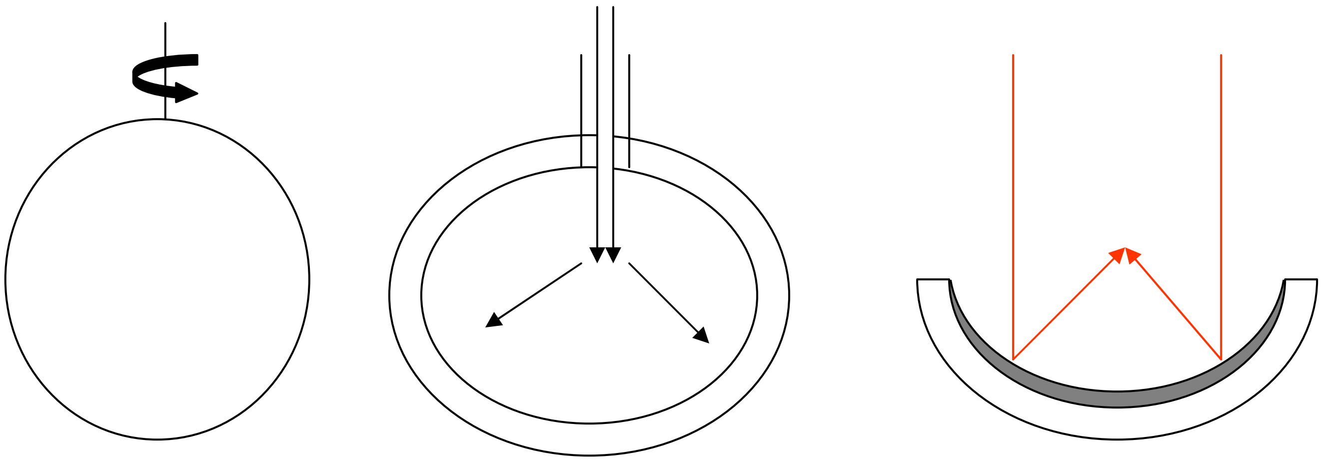


Figure 5.45. Stretch Blow Molding Process, Breakaway Section Showing Blow Mold with Stretch-Blow Pin (61). A: Stretch-Blow Pin. B: Air Entrance. C: Mold Vents. D: Preform, E: Stretch Rod Extended. F: Cooling Channels.

Stretched blow-mold apparatus

Blow molding in space using a spheroidal balloon structure

(1) Inflate balloon
(2) Rotate balloon to distort into spheroidal (approximately parabolic) shape
(3) Blow mold polymer into balloon
(4) Stop rotation, cut balloon in half, and coat inside with metal to create mirror



(1,2) (3) (4)

Coating organic and biological surfaces with shiny metal surfaces

Something that is well known: the Tollen’s test reaction, in which a silver ammine solution is reduced with organic acids or aldehyde to coat metal on a glass surface.

Coating biological surfaces with shiny metallic films: the Tollens reaction does not work, but we found a trick that does!

The trick is to precoat the surface with a solution of water/ethanol/tetrethyl orthosilicate, then dry at room temperature. Hydrolysis of the silicate produces a layer of SiO_2 on the surface. Subsequent exposure to the Tollens chemistry leads to formation of silver coating.

Multiple coatings can be used to generate thicker layers. We haven't characterized the surfaces yet, but they are probably a few 100 nm thick. This procedure works on any smooth biological and organic polymer surface that we have tried.

Silver coating of polymer surfaces: a small modification on the siloxane hydrolysis trick works here as well (surface needs to be pretreated with ammonia solution to bind the siloxane).

Here we coated Safety Glasses : Polycarbonate

Conclusions:

(1) It is possible to modify the size and shape of plants via hormones, but we don’t yet know how to control shape well enough to make a mirror directly from the growth of a single plant (or animal).

However we can grow biological structures that would provide the framework for the mirror, with a non-biological membrane attached to the framework to meet the optics requirements.

(2) Another option is to use self-assembly of non-biological systems such as polymers. This could lead to a light-weight spheroidal structure that can be fabricated into a mirror after coating with metal.

(3) We have developed a new method to coat smooth biological (or polymer) surfaces with shiny metal. This involves a wet chemical process that requires minimal materials other than the metal, water and a cheap organic materials such as dextrose.

Vacuum deposition can also be used to create metal films, but for large structures this is a more complex process.

We do not yet know if this produces optical quality materials without further processing.