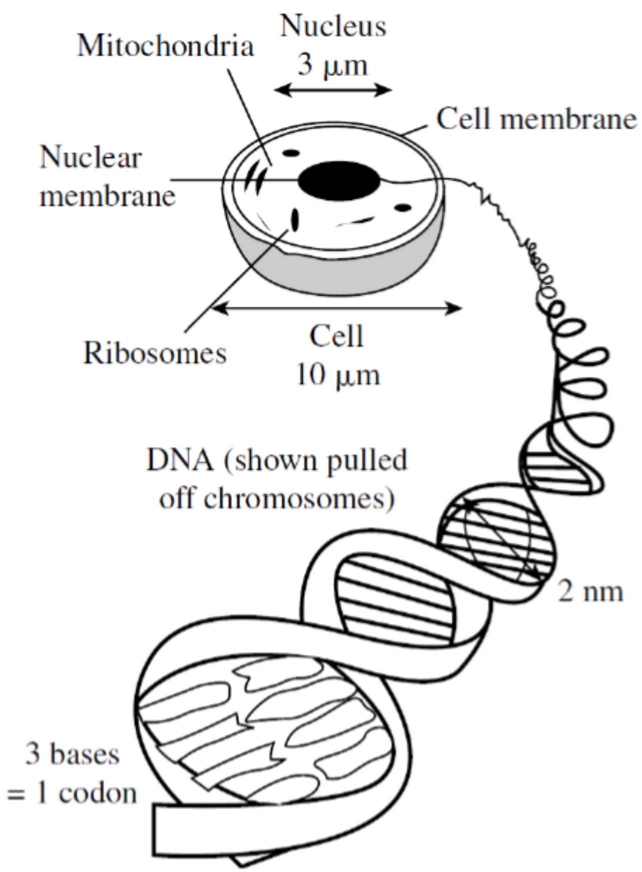
# 9. Bionanotechnology

# Repetition from the Last Lecture

- What are the 2 different types of catalysis (in terms of catalyst and reactant state)?
- What is chemical selectivity? Give an example.
- What is a hydrogen cell and how does it work?
- What limits the capacity of Li-ion batteries and the rate of charge?
- How can we generate electricity from "waste" energy?

# Molecular Biology

- A branch of biology that studies the cell biological processes at the molecular level (i.e. at nm). The cell itself can be considered a complex nanoscale device.
  - Mitochondria – energy production
  - Ribosomes – production of proteins (molecular motors) from amino acids linked by peptide bonds.
  - DNA – a program for making proteins

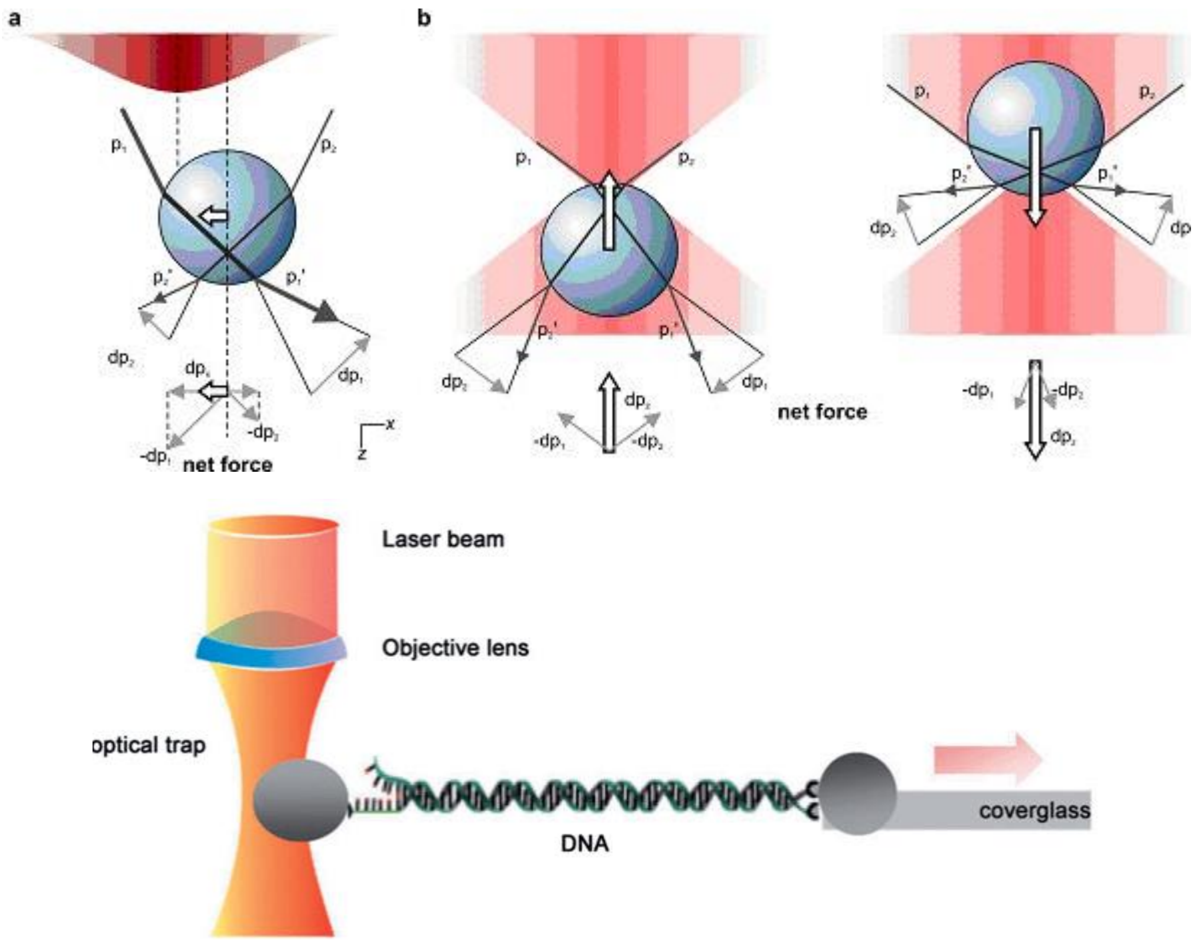


# Nanobiology

- Applying nanotechnology to biological systems with a view to achieving practical results
  - Separation and measurement of biological product properties (fluorescence using quantum dots, molecule mass measurement,...)
  - Biological material modification to improve their properties
  - Biomolecule manipulation (micro and nanofluidics, optical tweezers)
  - Use of biological molecules for new sensors or new applications

# Optical Tweezers

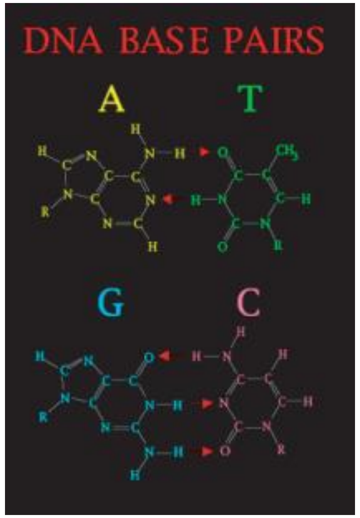
- A highly focused laser beam can stabilize small translucent objects (e.g. spheres) in its focus. The biomolecule stuck to the object's surface in the laser focus can then be manipulated – e.g. untangling a DNA molecule.

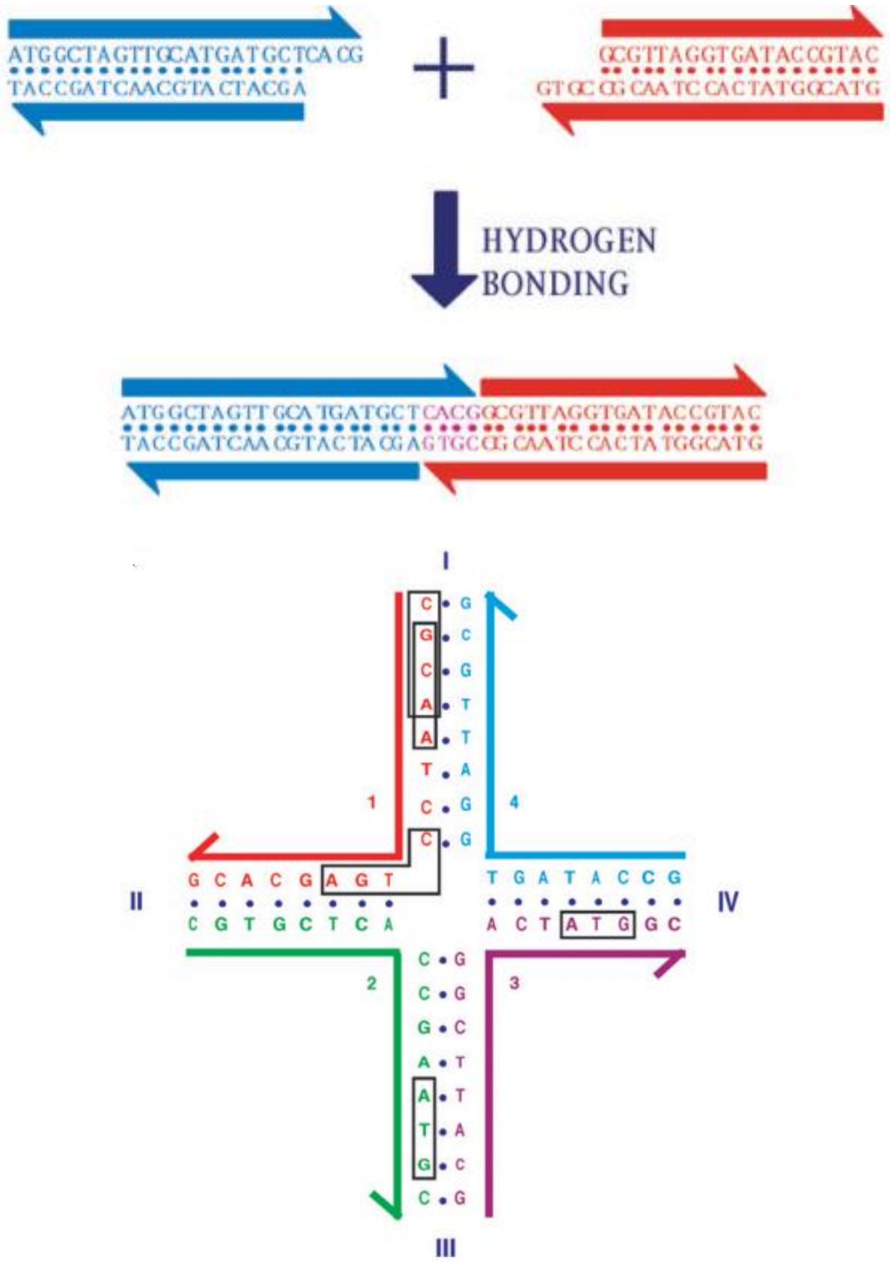



https://physicsworld.com/a/optical-tweezers-where-physics-meets-biology/
https://www.researchgate.net/publication/271222429_Progress_of_new_label-free_techniques_for_biosensors_A_review

# DNA Nanostructures

- The DNA molecule can be programmed to form junctions at a defined location in the polymer. This is very advantageous for the formation of self-organized nanostructures.

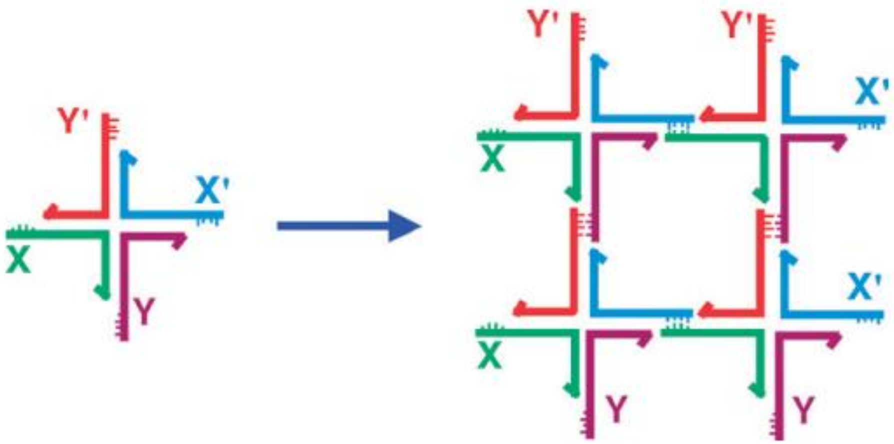


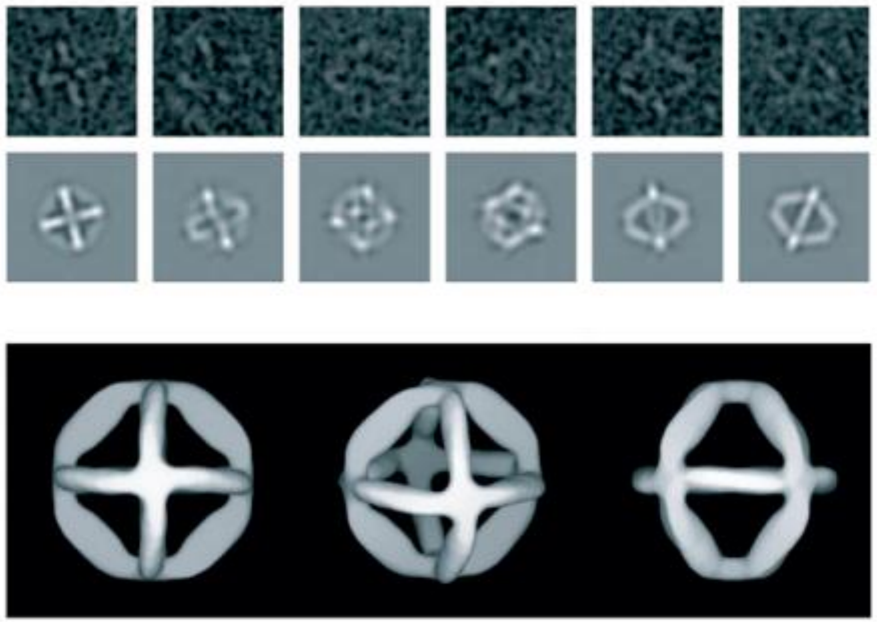

https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4141725/

# DNA Origami

- After synthesizing the appropriate DNA parts, the entire complex structure is formed in solution with virtually 100% yield.

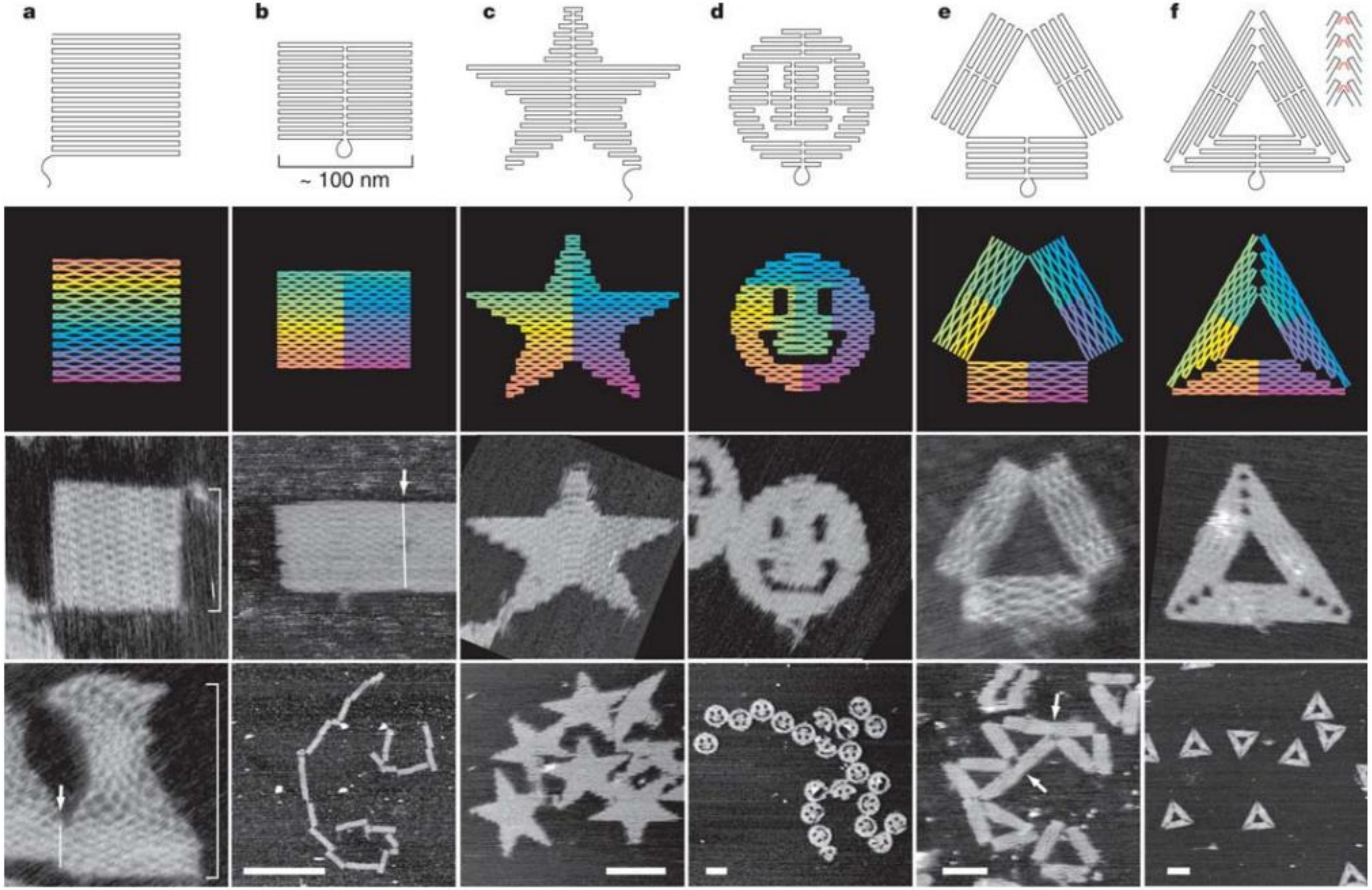



- DNA origami - one large DNA molecule folded by small DNA sections (helper strands) into the desired shape. The remaining sections are filled with DNA but without crosslinking.



https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4141725/

# DNA Origami



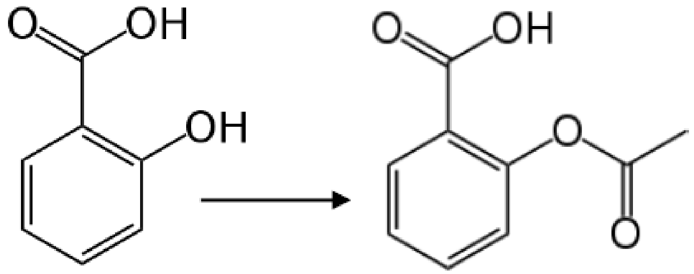

https://www.nature.com/articles/nature04586

# Biomimetics

- Emulation of the natural constructs for the purpose of use in new fields
- Macro biomimetics – bird wings, composites, dolphin locomotion (boundary layer manipulation in liquid), robotics
- Micro/nano biomimetics – drug development, neural networks, lotus effect, gecko effect, microactuators, hard structures, ...

- Wing:

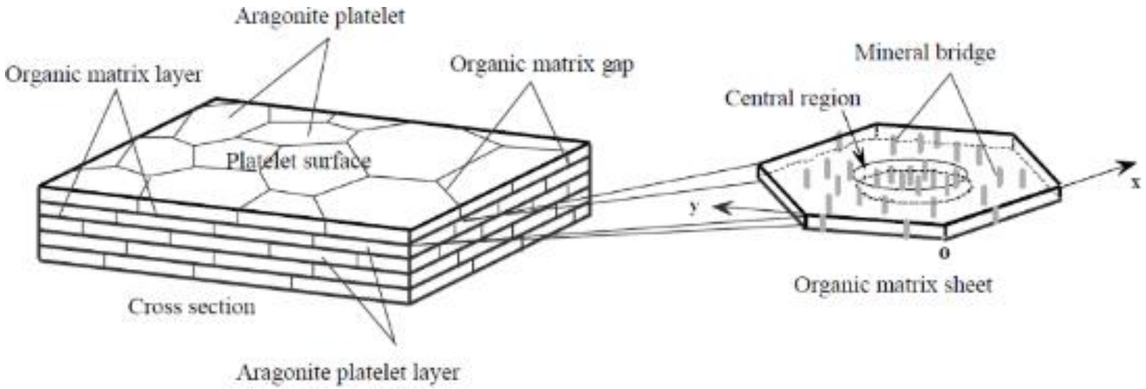
- Aspirin: Acetylsalicylic acid derived from salicylic acid (an extract of willow). Phenol-free, it no longer causes stomach ulcers with long-term use.

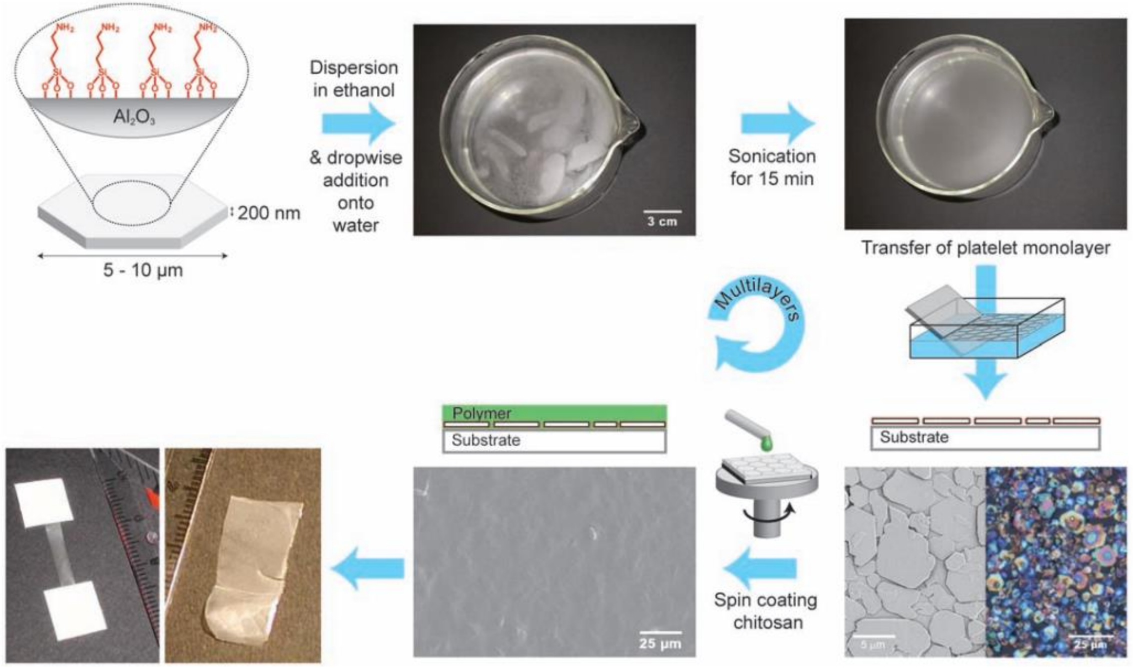



https://theaviationist.com/2013/03/19/an-unbelievable-image-seems-to-suggest-the-shape-of-the-b-2-stealth-bomber-was-inspired-by-mother-nature/

# Platelet Hybrid Film

- Due to its microstructure, the mussel shell is about 3,000 times stronger than the $CaCO_3$ from which it is made. The layers of aragonite platelets are glued together by a thin layer of protein that allows the layers to slide slightly over each other. Adjacent platelets are not glued together. Thus, a rupture of one platelet does not spread to the other platelets.

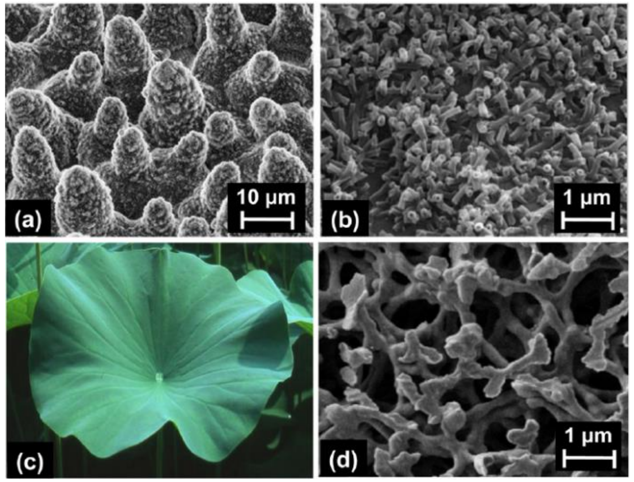


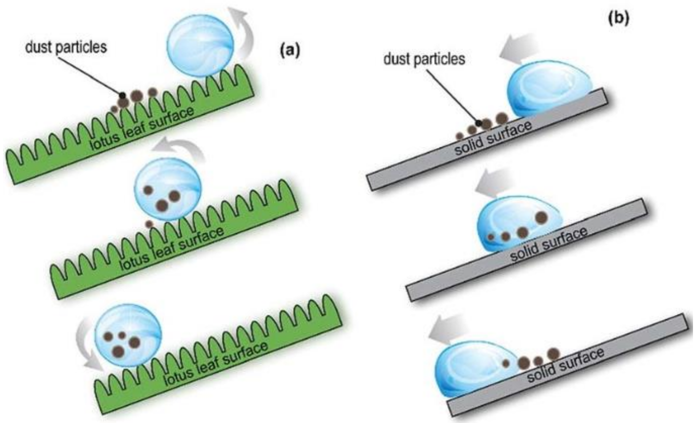




https://www.mdpi.com/2079-4991/3/2/242/htm
https://www.science.org/doi/10.1126/science.1148726

# Lotus Effect – Superhybrophobicity

- The water repellency and self-cleaning effect of lotus leaves, rose petals or insect legs is due to their nanostructure – needle-like structure.
- It keeps the leaves clean and dry. The rolling droplet packs dirt onto itself.

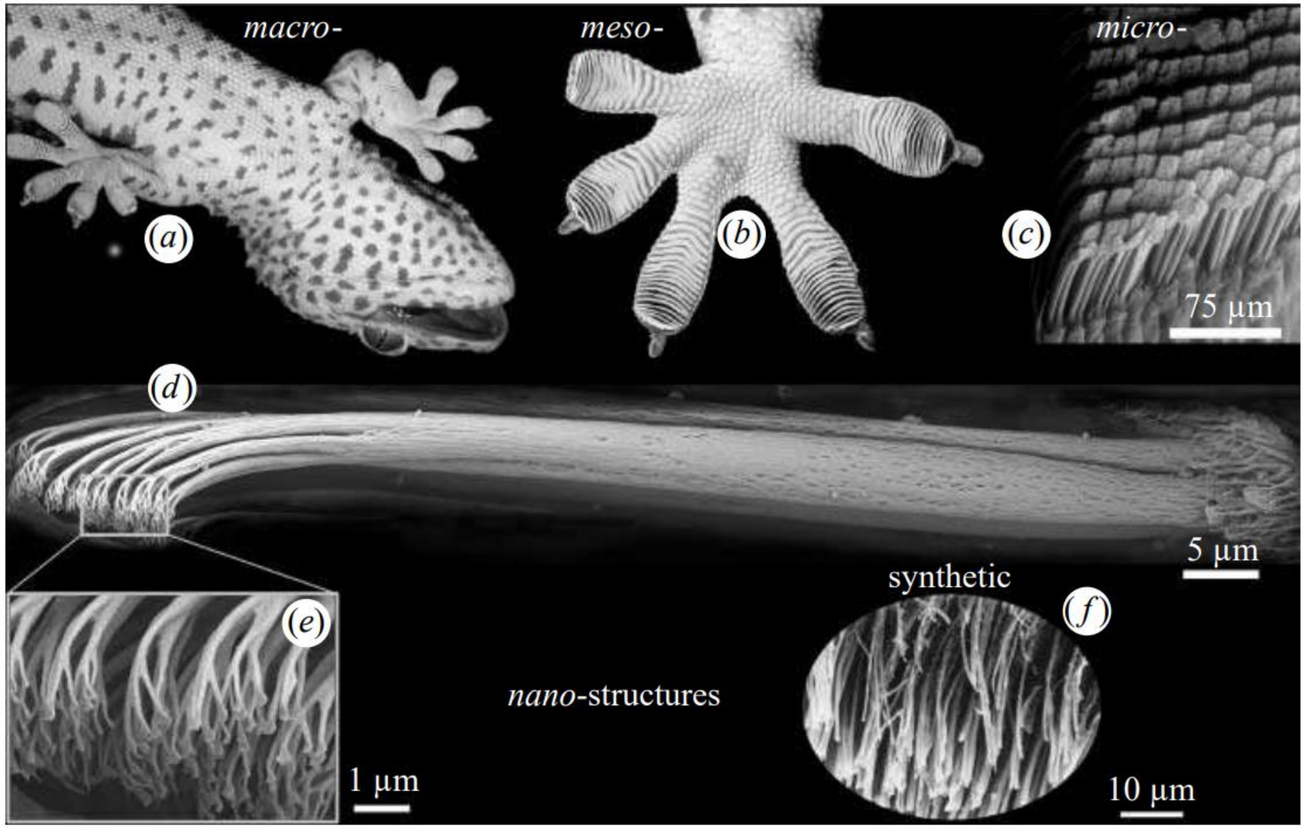



https://www.researchgate.net/publication/333974770_Bio-inspired_Sustainable_and_Durable_Superhydrophobic_Materials_From_Nature_to_Market
https://www.researchgate.net/publication/260168901_A_low_cost_safe_disposable_rapid_and_self-sustainable_paper-based_platform_for_diagnostic_testing_Lab-on-paper
https://br.depositphotos.com/stock-photos/gerris-lacustris.html

# Gecko Effect

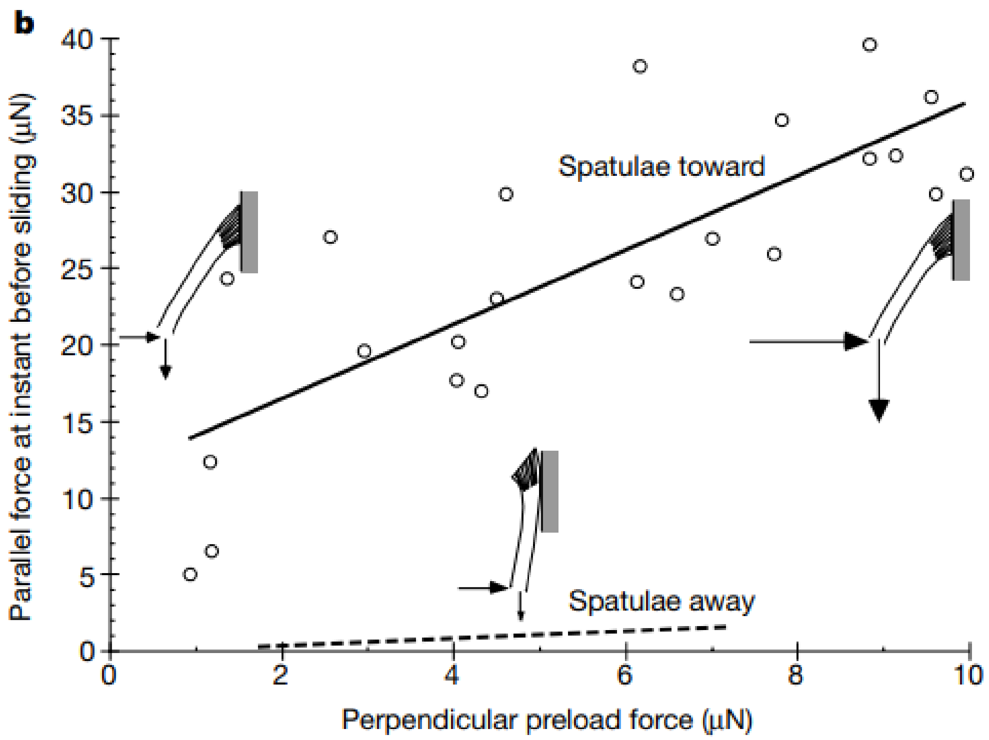
- Geckos can climb vertically and on glass without any adhesive. This is made possible by the "suction" lamellae on their feet (about 5,000 $mm^{-2}$). The lamellae do not stick to each other.




https://royalsocietypublishing.org/
doi/10.1098/rsta.2007.2173

# Gecko Adhesion Mechanism

- The adhesion is determined by Van der Waals (physical) forces after the spatulae are pressed against the surface. The gecko detaches from the surface by lifting the spatulae at an angle.
- Van der Waals forces – a common name for short range forces ($1/r^7$). They include:
  - Keesom force – between molecules with permanent dipole moments
  - Debye force – a molecule with a permanent dipole moment induces a dipole moment in an adjacent molecule by polarization
  - London dispersion force – instantaneous dipole moment given by the motion of electrons in the molecule. They are present in all molecular interactions.




https://www.nature.com/articles/35015073

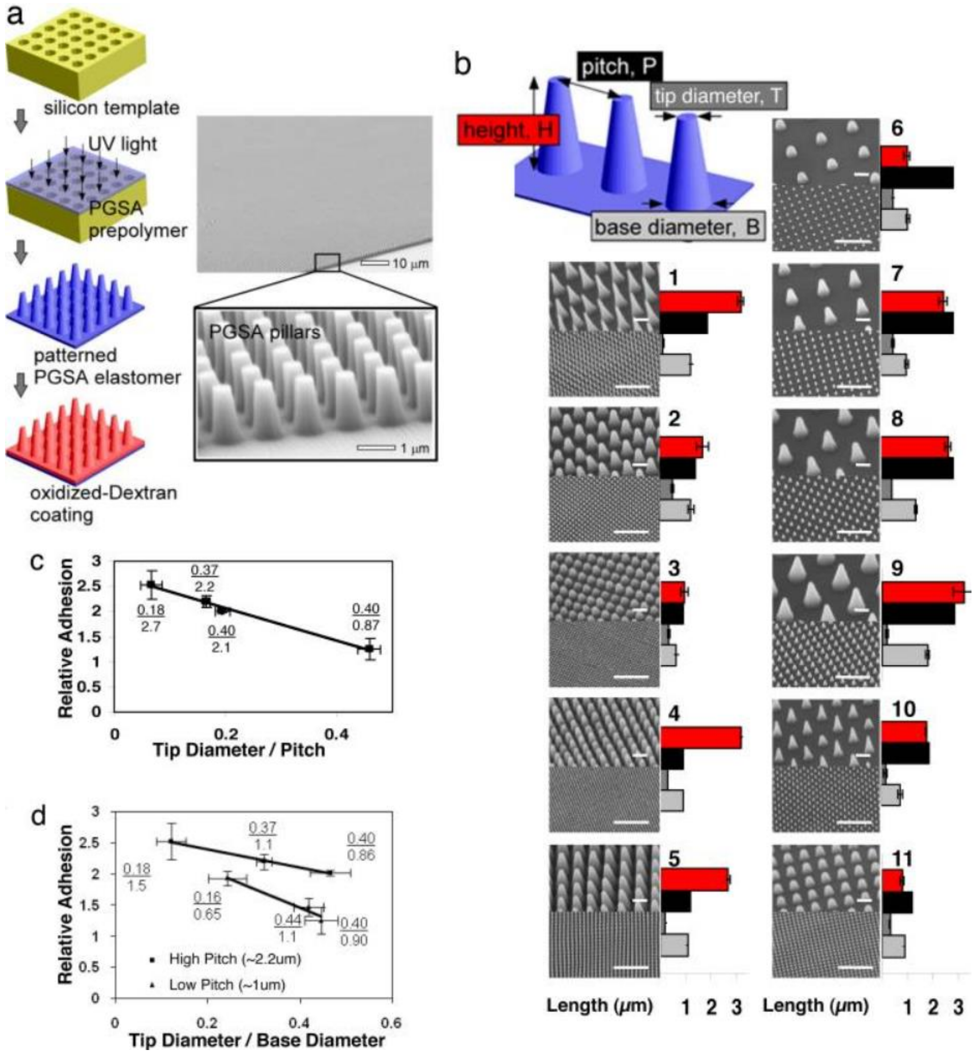
# Medical Applications of Gecko Adhesion

- In surgery, there is a demand for a strong biodegradable patch that adapts to various mechanical deformations (e.g. heart) while still retaining adhesion to the tissue it covers.
- An example from MIT – a gecko adhesive made from the biodegradable elastomer PGSA – poly (glycerol-co-sebacate acrylate):

(a) Nanocasting into a photolithographically prepared Si mold + UV curing + spin coating with dextran (adhesive)

(b) Various gecko structures

(c) (d) Adhesion test results



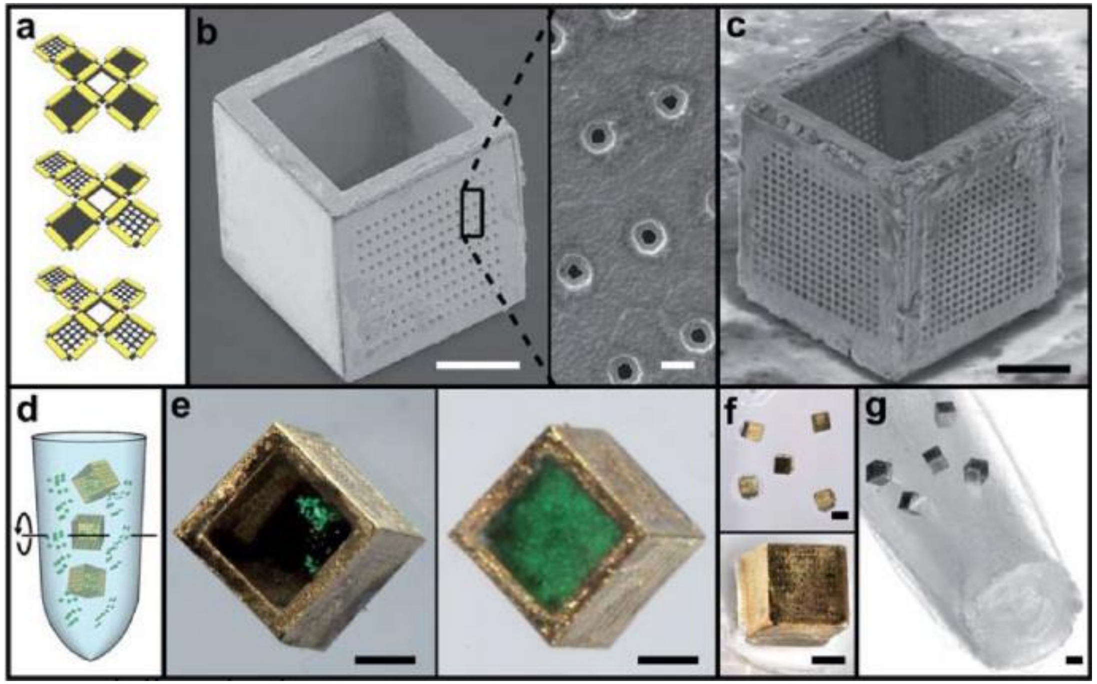

https://www.ncbi.nlm.nih.gov/pmc/articles/PMC2268132/

# Medical Nanotechnology

- The modern understanding of medicine is based on the idea of the metabolism control by a complex communication network mediated by molecules (cellular communication) that control and coordinate cellular activities.
- Nanomedical research focuses on:
  - New materials for restoring cell growth (scaffolding) and tissue repair (nerve repair, ...)
  - Improving diagnostics and imaging (nanomagnetism, quantum dots, biological sensors,...)
  - Improving drug delivery (targeted dosing, pacemakers,...)
  - Understanding and controlling biomolecular mechanisms (tailor-made molecular enzymes)
  - Discovery of new therapeutic effects of nanoscale systems (including biosystems) – e.g. ferrofluid in the treatment of retinal detachment, plasmons, new types of patches,...

# Nanoencapsulation

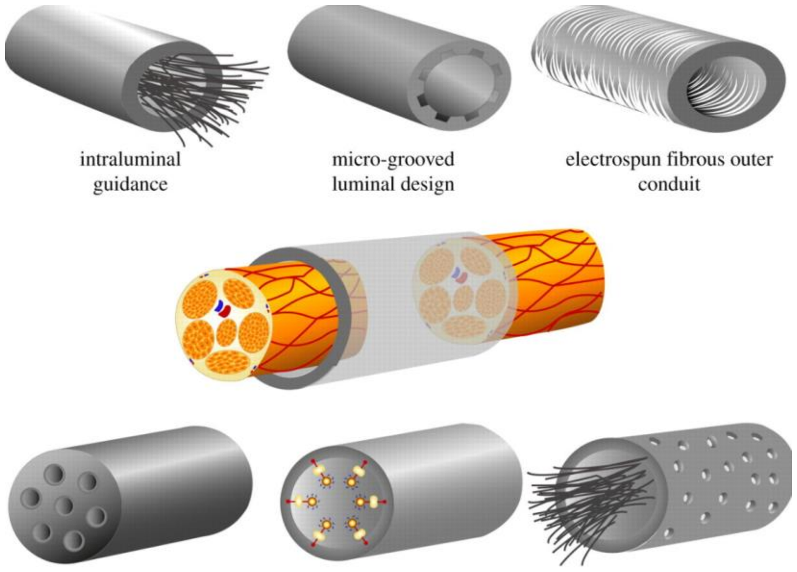
- For example, insulin is administered subcutaneously because it would not pass through the digestive tract. Drugs to the brain are unable to cross the blood-brain barrier. Coating the molecule with a suitable material – nanoencapsulation – is one possible solution for drug delivery.
- It is also possible to encapsulate living cells to avoid an immune reaction of the organism. E.g. pancreatic beta cells producing insulin in a self-contained container.

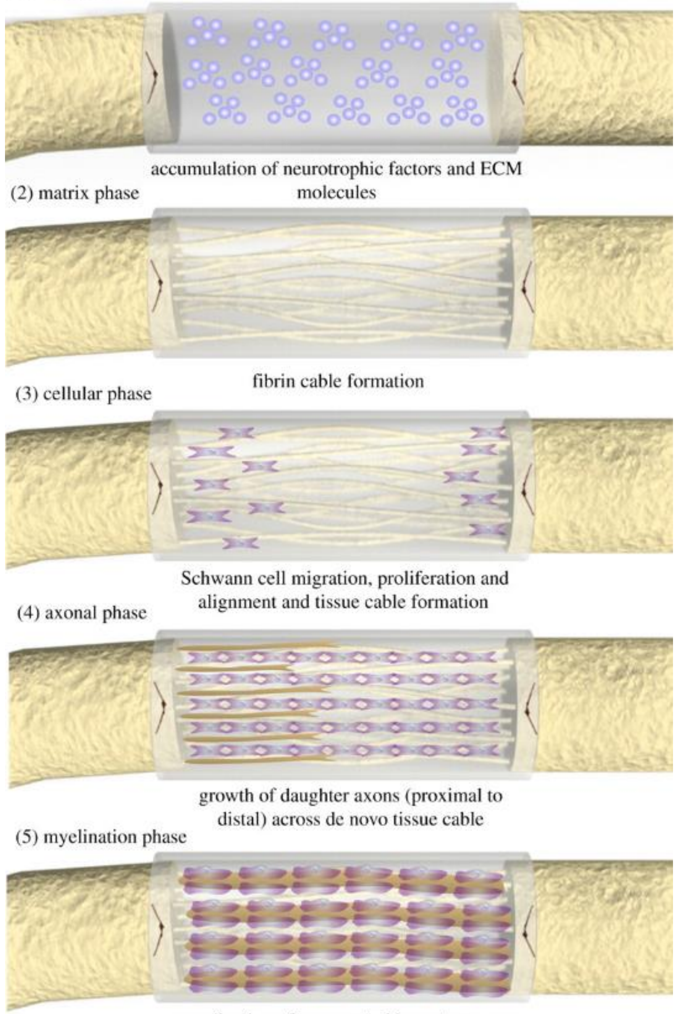



https://pubs.rsc.org/en/content/articlelanding/2011/lc/c0lc00368a

# Restoring Damaged Peripheral Nerves

- The peripheral nervous system has the ability to regenerate axonal nerve fibres (axons) over short distances. Regeneration over longer distances can be promoted by a suitable support structure (tube), which can also be impregnated with growth activators.

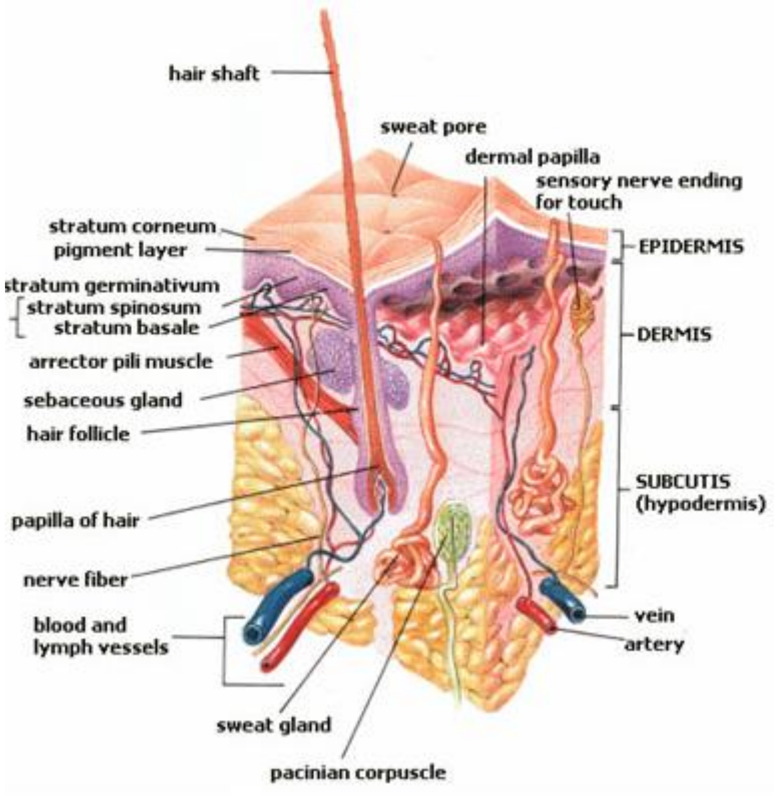



https://royalsocietypublishing.org/doi/10.1098/rsif.2011.0438

# Artificial (Electronic) Skin

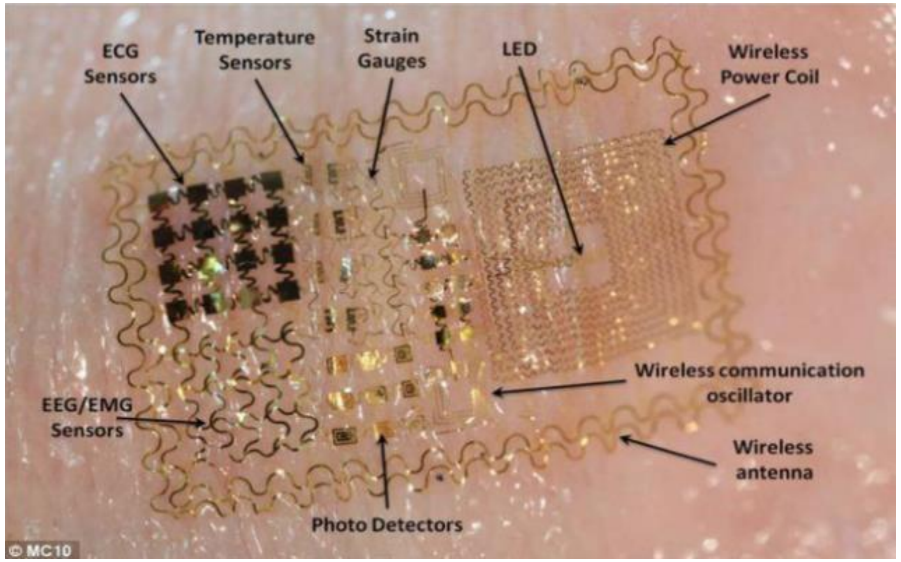
- Human skin
  - Largest organ with an area of ~1.7 $m^2$
  - Protects against microbes, prevents infection, metabolizes vitamin D to build calcium into bones, regulates body temperature.
  - It's a huge sensor – pressure, heat, cold, pain.
  - Elastic, self-renewing (dead cells on the surface are gradually renewed by cells coming from deeper layers).




https://www.wikiskripta.eu/w/K%C5%AF%C5%BEe

# Artificial (Electronic) Skin

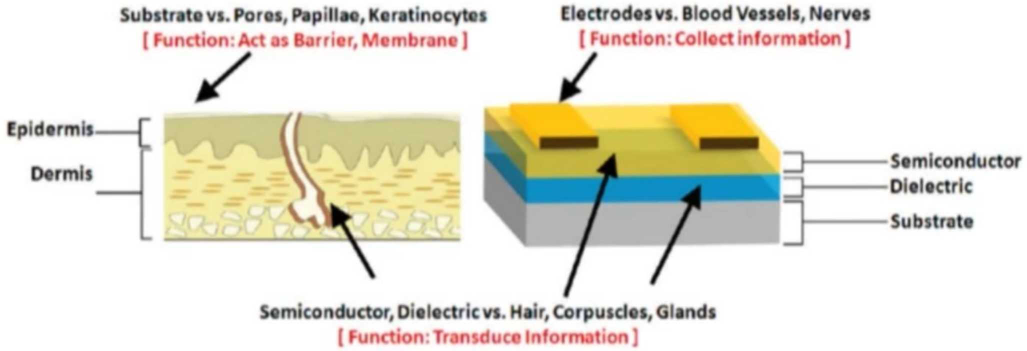
- The concept of artificial skin was developed for robotics - the ability to perceive pressure - the problem of lifting an egg. Most standard robots only have a rudimentary sensor – there is a yes/no contact.
- Further development for prosthetics  – there must be a sensor at least
  - Elastic
  - With full sensitivity in the range of 5 – 100 mN with a linear response
  - With a spatial resolution of 1 – 2 mm




https://www.semanticscholar.org/paper/Flexible-Electronic-Skin-Thakur-Dofe/647b6302b5c3a67ba212597631722f12b5ded035

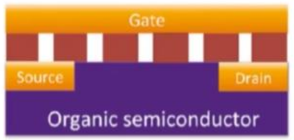
# Artificial (Electronic) Skin

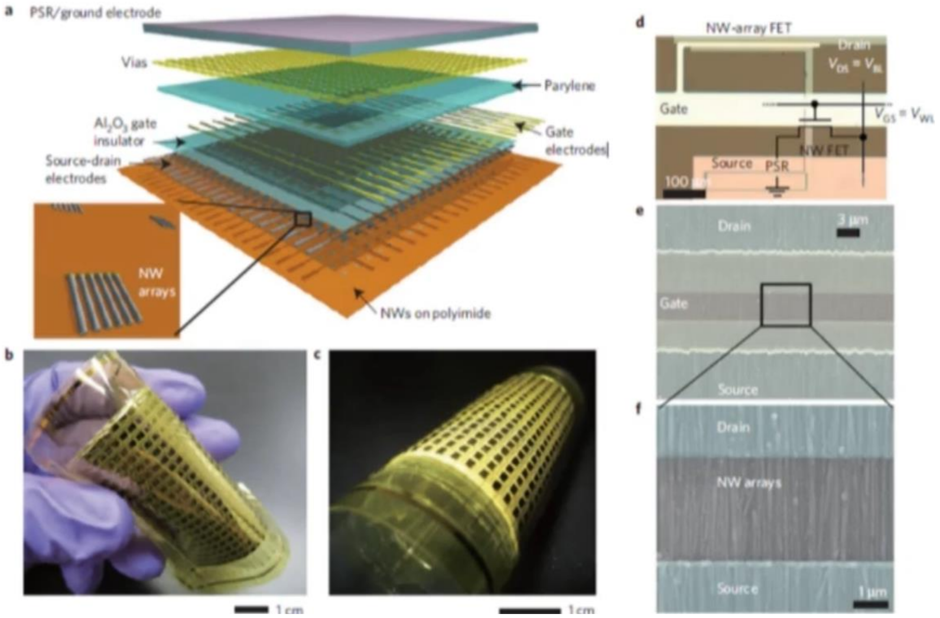
- Using the similarity of the sensor apparatus with the properties of organic FET transistors.



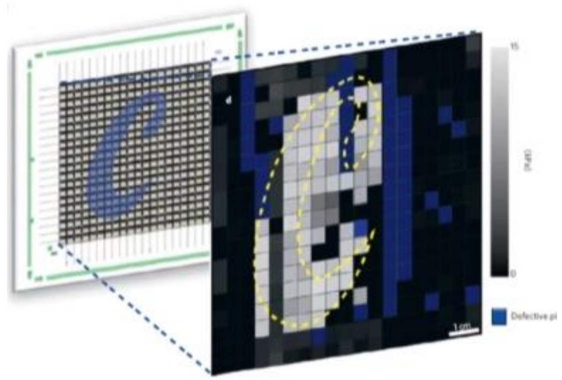

(A)


(B)



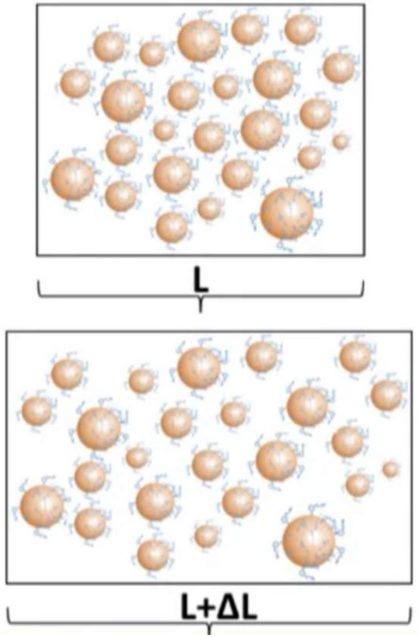



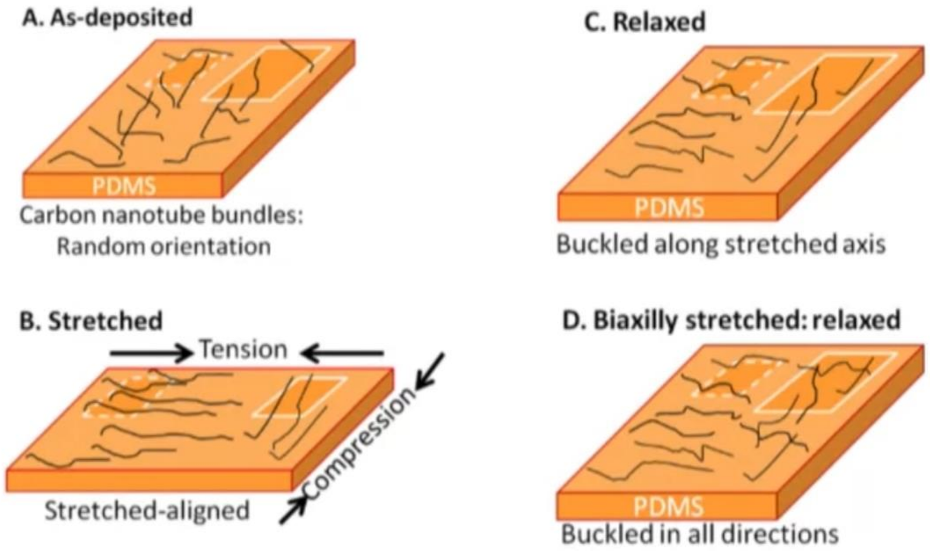

3 cm$^2$



# Artificial (Electronic) Skin

- Using functionalized nanoparticles or carbon nanotubes (tunneling current dependent on particle distance)




Revolution of morphology of films of carbon nanotubes with: **(a)** stretching; **(b)** under strain; **(c)** stretched and released along one axis; **(d)** and stretched and released along two axes.

# Conclusion

- Nanotechnology in molecular biology (itself a "nano" discipline) seeks, among other things, to combine the proven functionality of biological systems with the capabilities of microelectronic technologies.
- Biomimetics uses reverse engineering methods to understand systems developed by evolution over 4 billion years. Nanotechnology allows us to mimic many systems.
- Medical nanotechnology enables active treatment at the macromolecular level and the design of qualitatively new implants.