Global Focus on Knowledge

Production and Application of Materials

The University of Tokyo Hiroshi Komiyama

Lecture One: The production process of matter, e.g., metals (iron and steel).

Lecture Two: Conjugation (device), e.g., semiconductors and inorganic materials.

Lecture Three: Soft matter, e.g., liquid crystals.

Lecture Four: Matter in durable earth (device), e.g., fuel cells and biochips.

1. Overview

- Examples of application : Liquid crystal displays, color films, color filters, and molecule sensors

- Materials (molecular structure and molecular design), structure (shape), velocity(multi-layer application and inkjet), and conditions

- Phenomena

  Self-organization, chemical reaction, and (interfacial tension-driven) flow

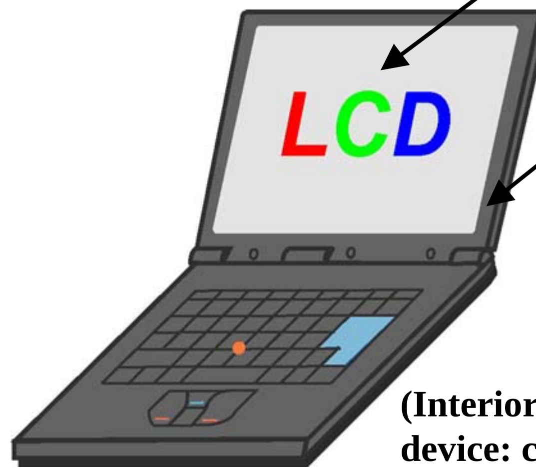
Soft Matter

Liquid crystal

Organic low molecule

Computer

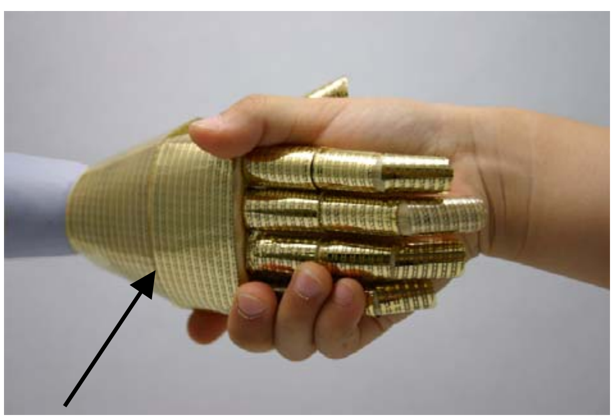
Liquid crystal display



Plastic molding product

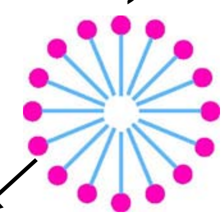
(Interior of semiconductor device: conductive polymer in the future?)

Robot



Conductive polymer

Micelle (soap and cosmetics)



Amphipathic organic molecule

Properties of Soft Matter

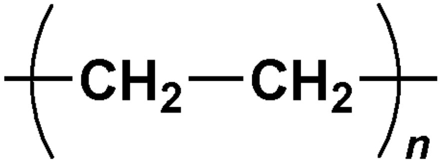
	Organic material	Inorganic material	Metal
	Soft matter	Hard matter	
Structural unit	Molecule	Atom	
Functional expression	Monomolecular Molecular assembly	Atomic assembly	
Bonding force	Intermolecular force (relatively weak)	Covalent bond (relatively strong)	Metal bonding

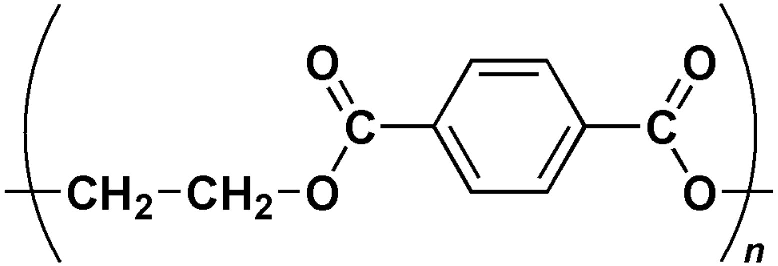
2. Soft Matter as Structural Materials

Polymer

Polyethylene

Polyethylene terephthalate (PET)





Injection Molding Process

Synthesis from petroleum (PET synthesis)

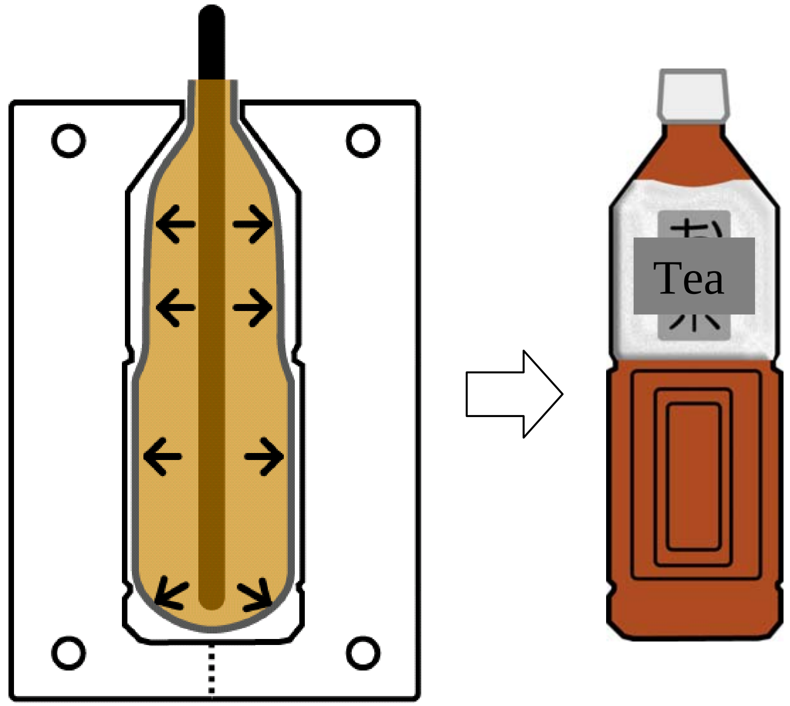
Thermal dissociation

Mold injection

Air blow

Cooling

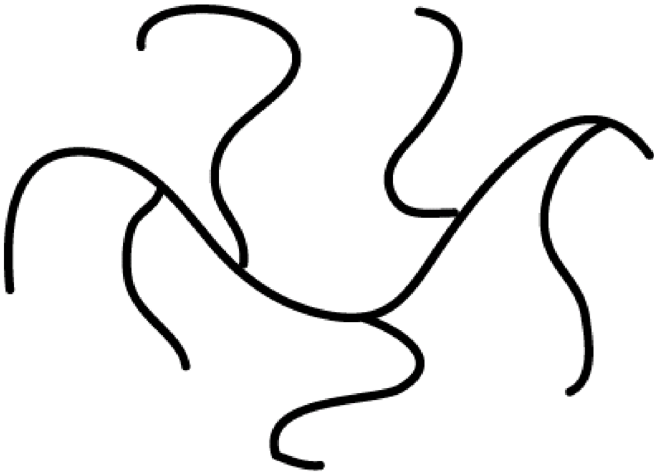
Removal



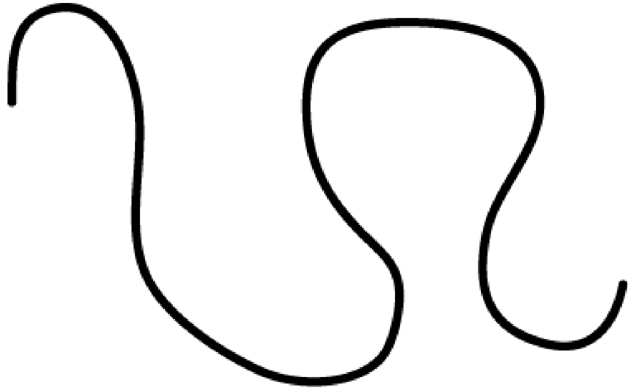
Injection molding

Reaction Process and Molecular Structure

- High-pressure oxygen radical polymerization
  → Irregular structure
  (cross-branch structure)

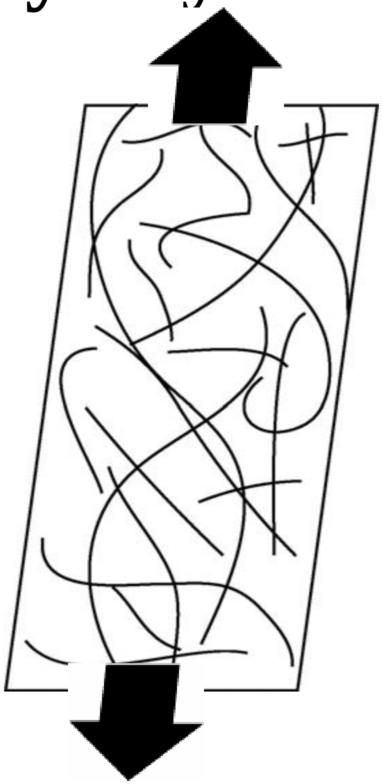


- Low-pressure catalytic polymerization
  → Regularly arrayed structure
  (straight-chain structure)



Molecular Structure and Physical Properties

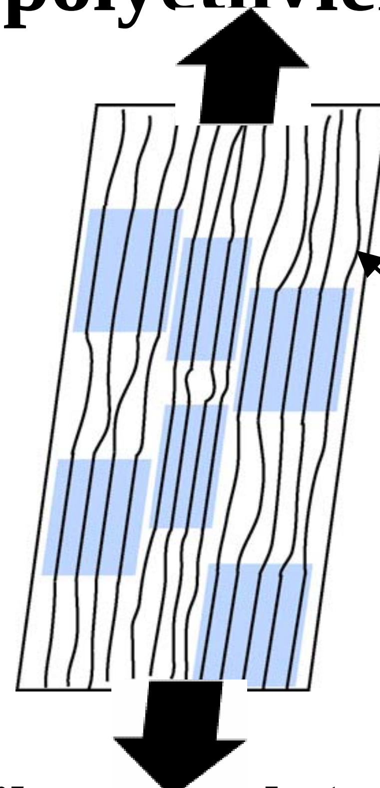
Cross-branch polyethylene



Difficult for molecules to arrange themselves

Straight-chain polyethylene

Spinning to give arrangement

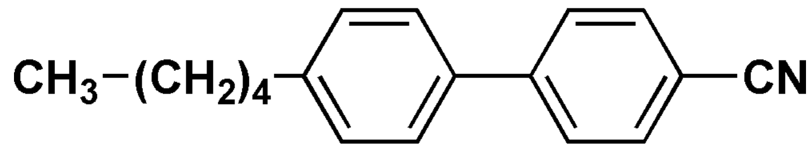


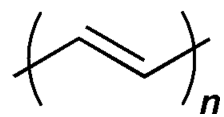
Crystalline region

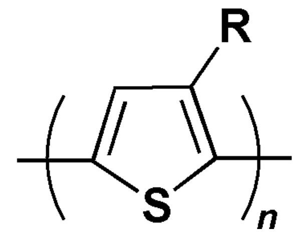
- Soft (used for film)
- Transparent

- High tensile strength (used for fibers)
- Opaque

3. Functional Soft Matter

Liquid crystal 

Semiconductors 

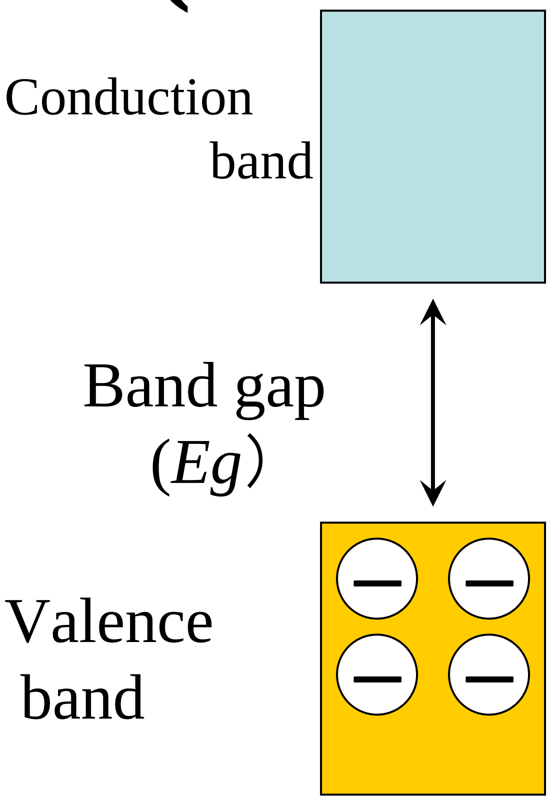


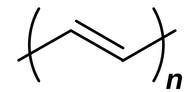
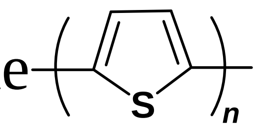
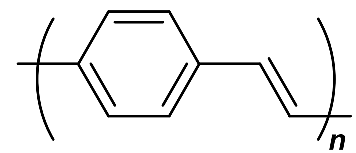
(Electro-conductive polymers)

Functional devices (molecules)

Films (multi-layer and functionality), fibers, and compound devices

Semiconductors
(Electro-conductive Polymers)



	Chemical compound	Eg (eV)
Electro-conductive polymer	Polyacethylene 	1.4
	Polythiophene 	2.0
	PPV 	2.5
Inorganic	Si	1.12
	GaAs	1.42

- Semi-conductive polymers enable molding processing approached easily.
- Tuning of Eg can be achieved by chemical modification.
- High conductivity appears by doping; high as metals.

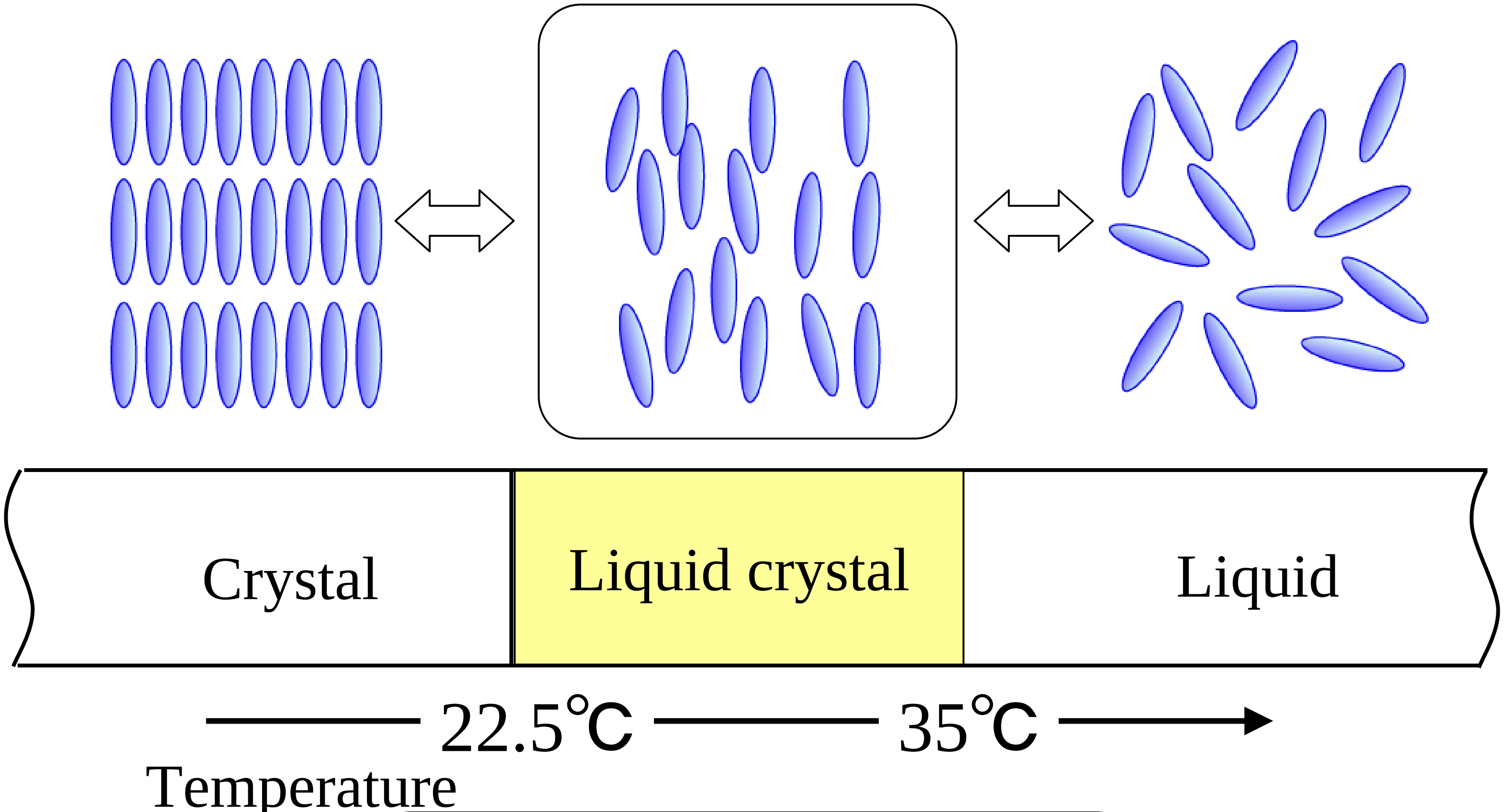
Polymeric Semiconductors

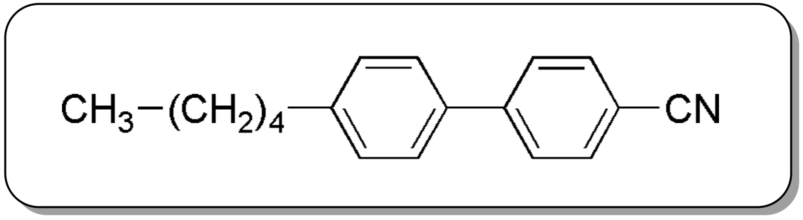
	Polymeric semiconductor	Silicon (inorganic) semiconductor
Basic characteristics	p-type and n-type semiconductors/pn junction Light emitting diode Field effect transistor	p-type and n-type semiconductors/pn junction Light emitting diode Field effect transistor
Advantageous characteristics	Soft, area enlargement, easy to control physical properties by changing the chemical structure, and light weight	Hard, outstanding durability High reliability

Capability of polymeric semiconductors:

- Bendable like paper, images depictable and erasable devices ➡ Electronic paper
- Molecular level (nano-size) ➡ Sensor systems such as ultra-micro complex devices and biomolecules.
- Structure similar to biomolecules ➡ Fault tolerance

Liquid Crystals





3.1 Process Example 1

Micrometer-sized Structure Making in Direction of Thickness

Multi-layer Deposition of Photographic Films

Figure removed due to copyright restrictions

Images provided by Fuji Photo Film Co., Ltd.

Multi-layer Deposition by Multi-layer Coating

Factors:

- Laminar flow control
- Diffusion control of longitudinal direction
- Drying process control

3.2 Process Example 2

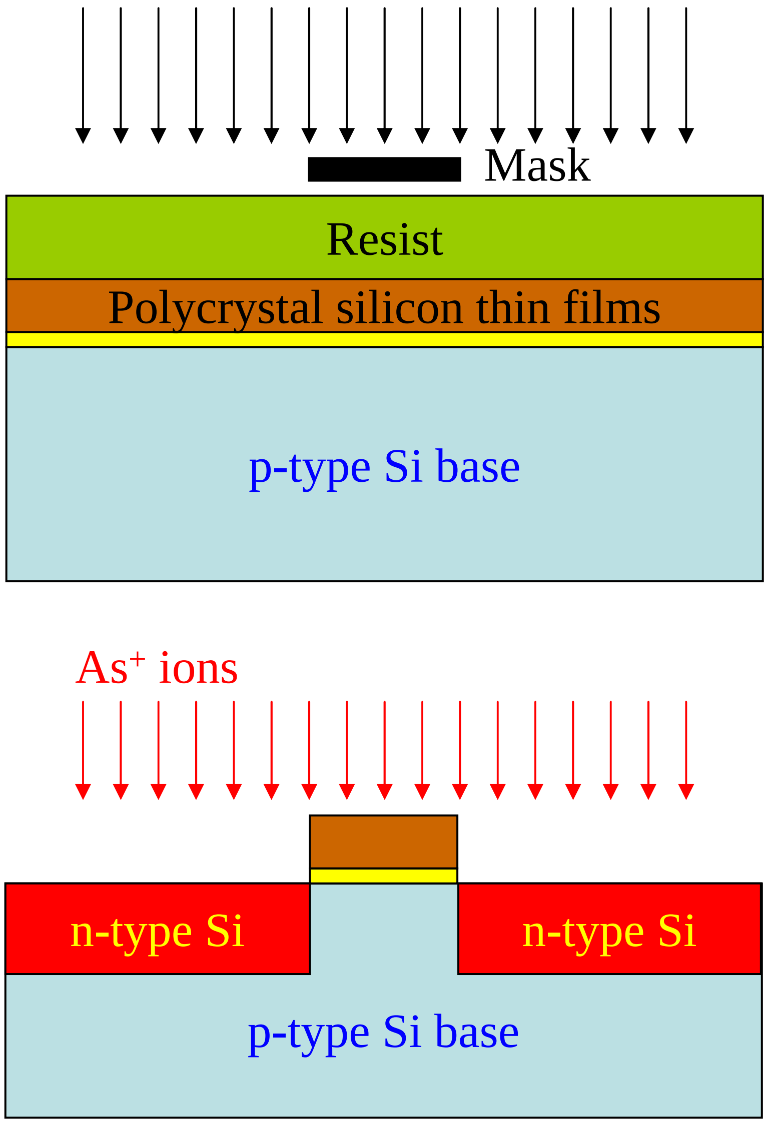
Micrometer-size Structure Making in Plane Direction

Top-down and Bottom-up

Scrape off from solid phase
“Top-down method”

Assembling the molecule-by-molecule
“Bottom-up method”

Top-down Method (Review)
(Silicon Semiconductor Lithography)



Bottom-up Morphogenesis Example 1: Color Filter

Micro-size dot alignment

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Inkjet printing

Color Filter Making by Inkjet (Bottom-up Process)

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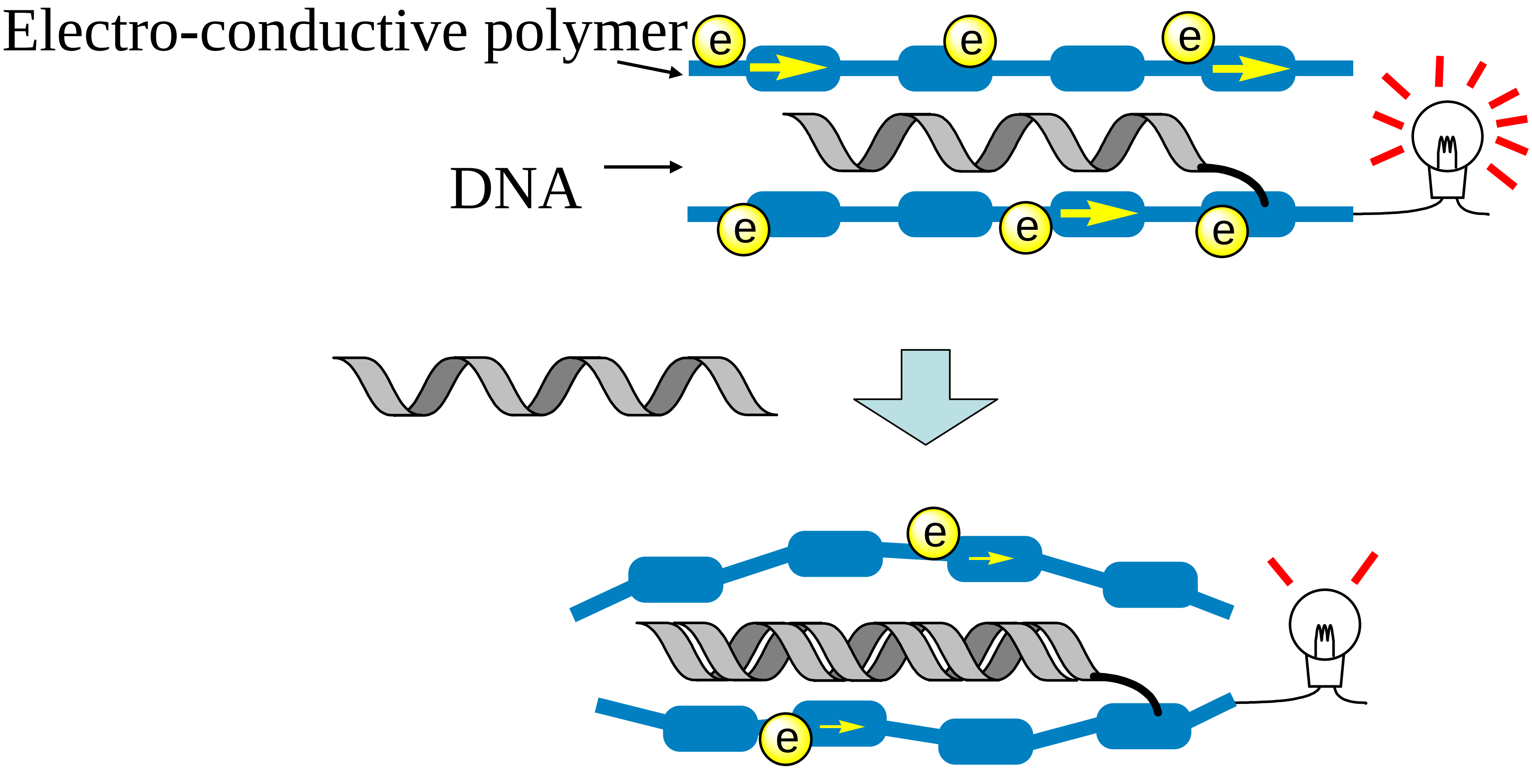
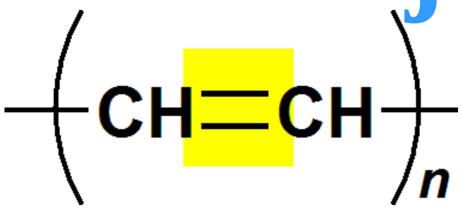
4. Functional Devices and their Formation Process

E.g., DNA sensors

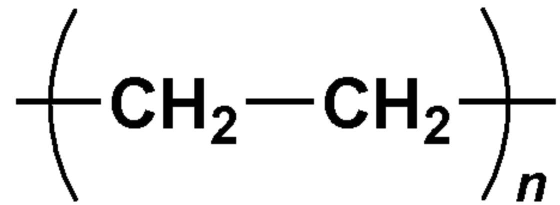


Chemical Structure of Soft Matter with Semi-conductive Properties

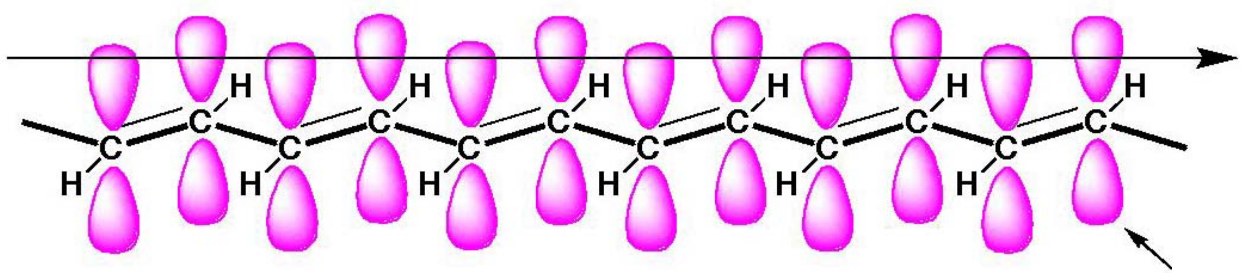
Conjugated Structure



Polyacethylene
(conductor)
(Conjugated structure)



Polyethylene
(insulator)
(No conjugated structure)



Electron cloud

Polyacethylene

Characteristics of Functional Soft Matter

- Flexible
- Large area
- Bio-interface

Pending problems:
durability and stability

4.1 Bottom-up Process

Printing technology

Painting directly by ink

Printing (Circuit Making)

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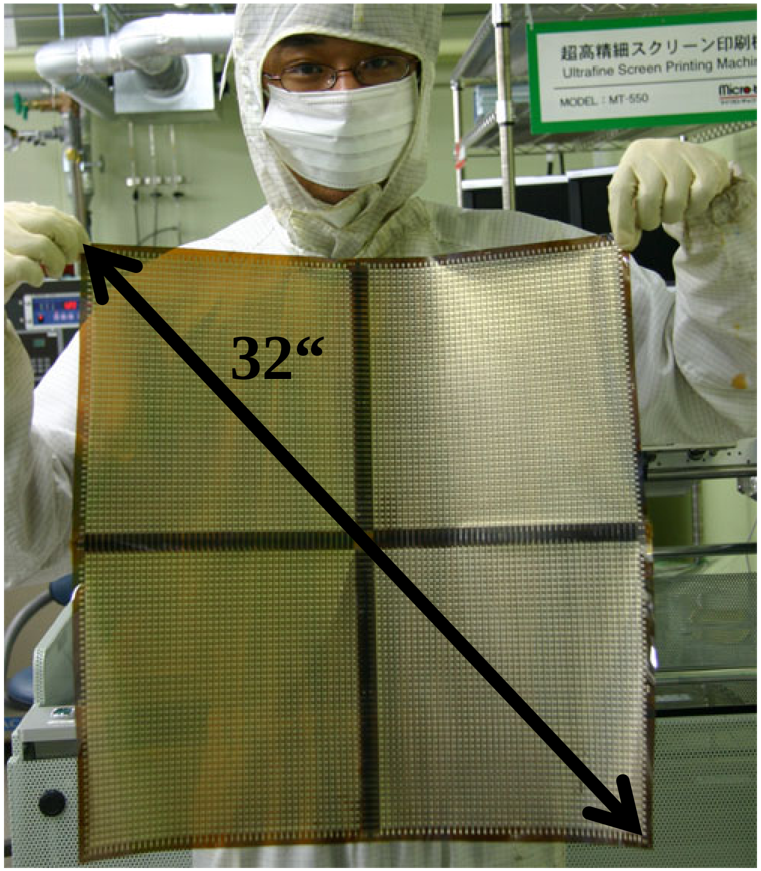
4.2 Application to Artificial Electronic Skins

Channel length L=50μm



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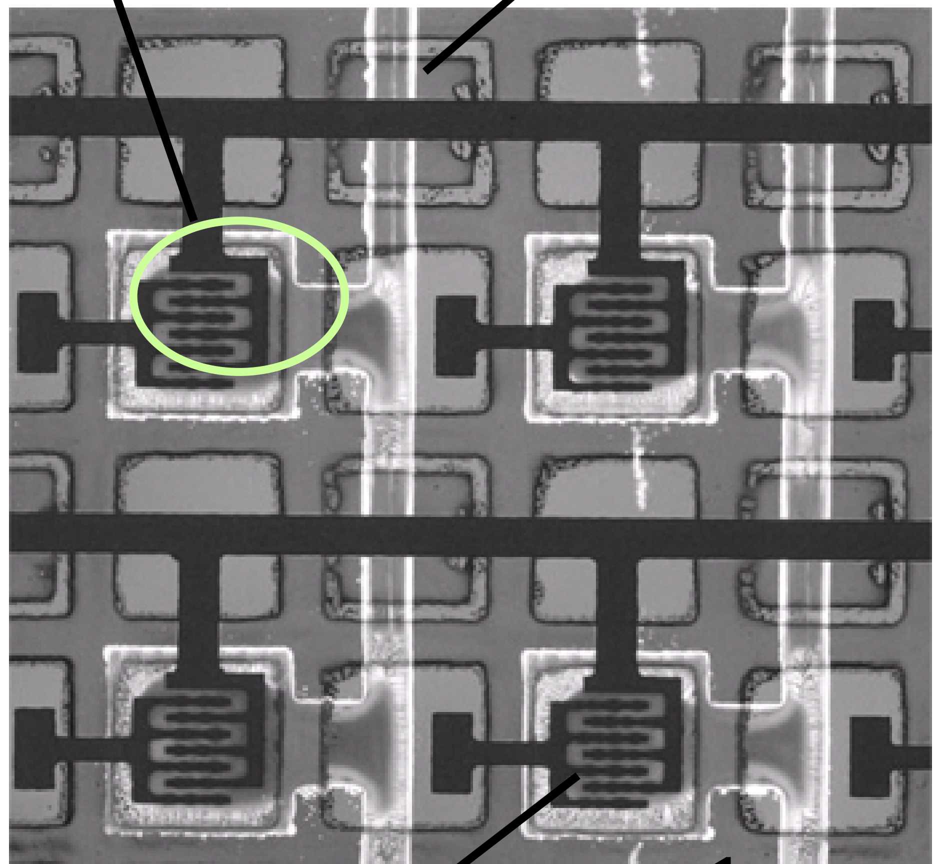
Electro-conductive polymer

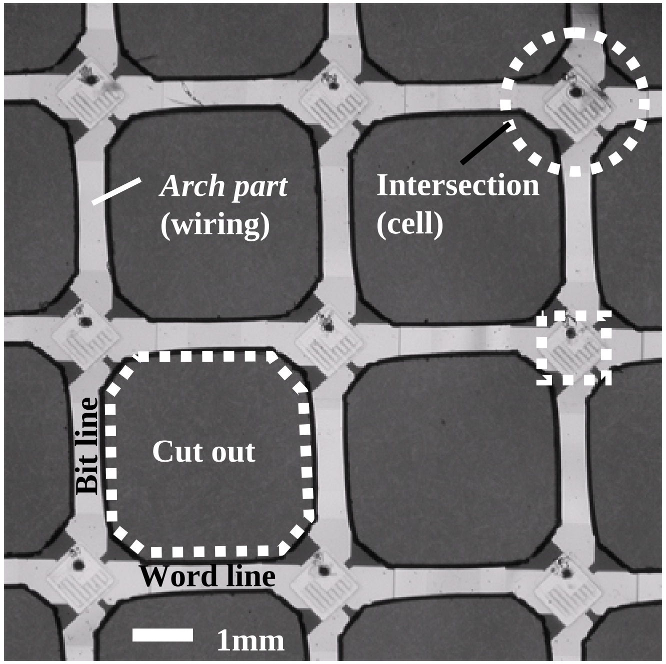
Wiring (silver nano-particle)



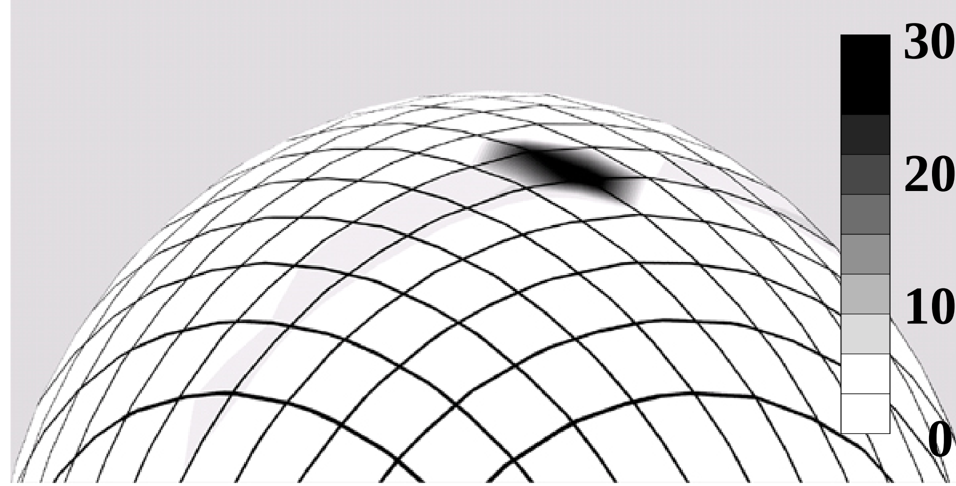
1mm

Gate insulator (polyimide)

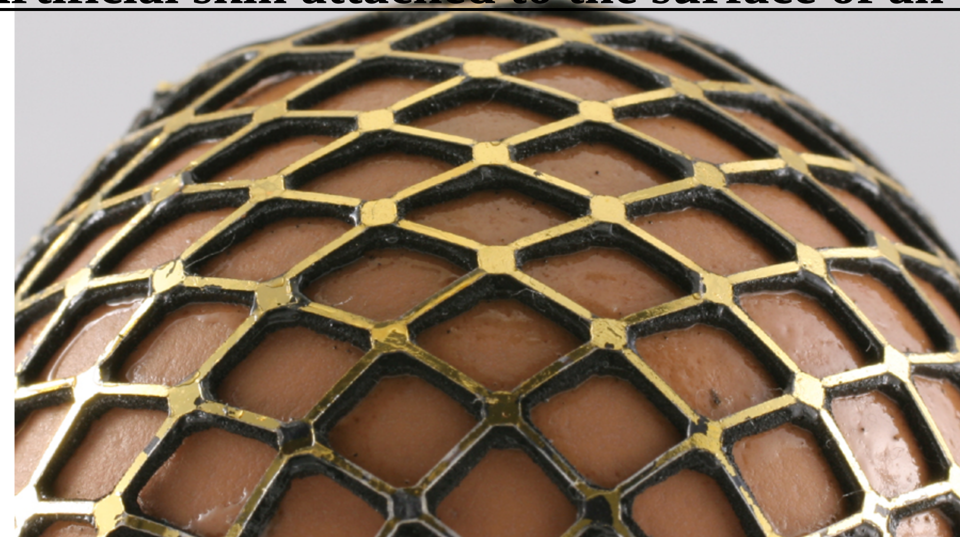
Stretchable Artificial Electronic Skins

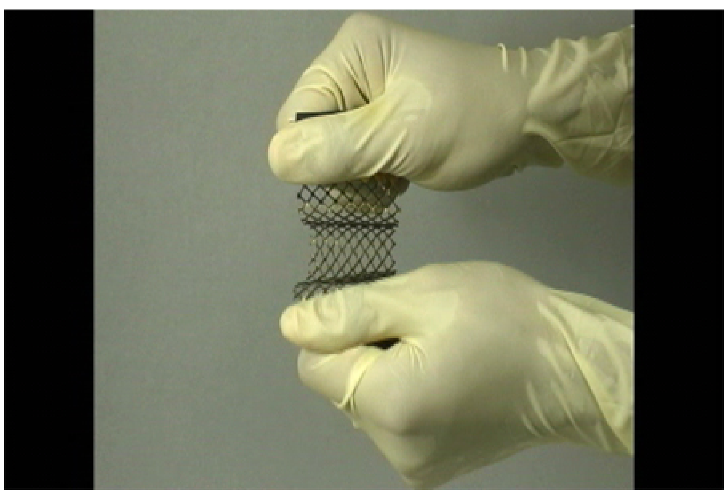


Pressure distribution measurement



Artificial skin attached to the surface of an egg





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A Robot Hand with Human Cutaneous Sense

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(*TIME,* November 21, 2005)

Figure removed due to
copyright restrictions
(*TIME,* November 21, 2005)

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4.3 High Speed Process

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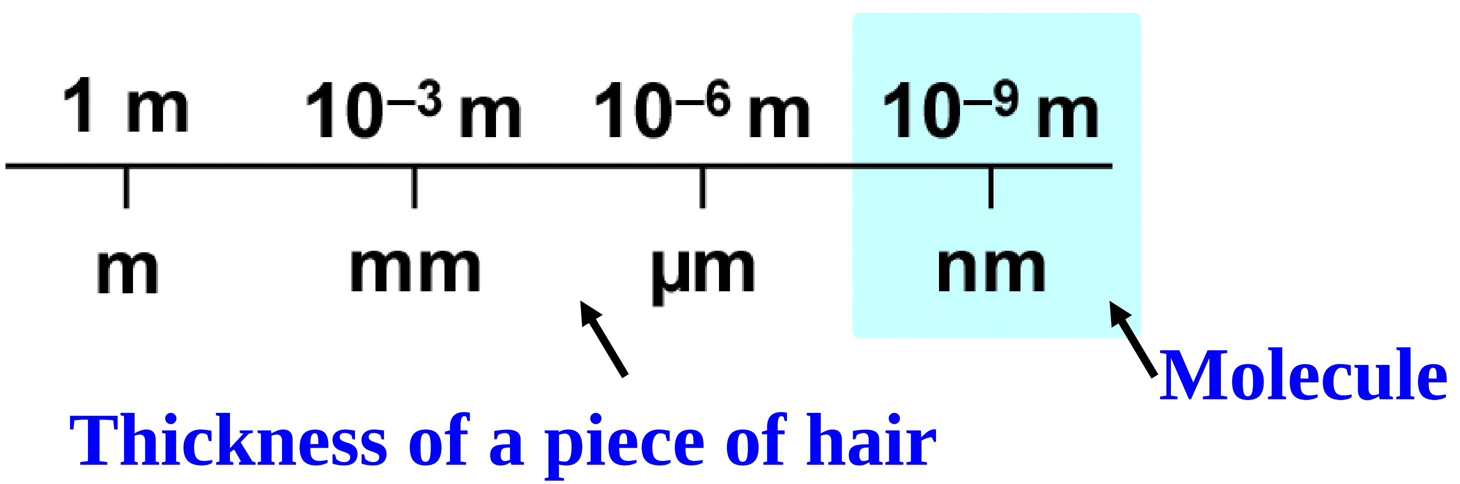
5. Manufacturing at the Nanometer Level

Functional expression by molecular designing

Nano-size device integration

Self-organizational structure formation process

Large area and flexible devices



5.1 Self-organization Phenomenon

Molecules and atoms (cluster) spontaneously form the structure while maintaining the unit of the structure.

Future expectations:

- Accurate formation of the structure
- Energy conservation process
- Low environmental burden

Categories and Examples of Self-organization phenomenon

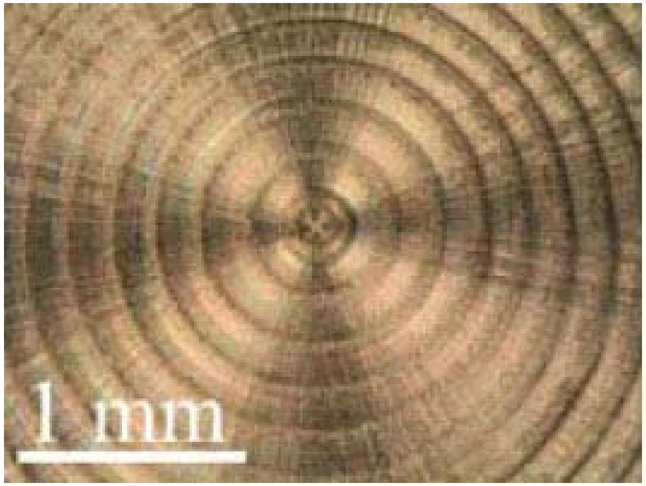
Thermo-dynamics	Equilibrium	Non-equilibrium open system
Examples	Crystal Liquid crystal Self-organization of membranes Phase separation	Turing model Belousov-Zhabotinsky reaction Liesegang ring Wind-ripples formed on sand Stripe patterns of tropical fish Forests

Examples of Self-organization

- Thermodynamically-non-equilibrium systems
(Sand dunes, forests, and oscillation in chemical reactions)

Grow as solvent evaporates.
Crystal of ascorbic acid
(Liesegang ring)

Wind-ripples formed on Tottori Sand Dune



‡ Source: Prof. Mitsugu Matsushita, Faculty of Science and Engineering, Chuo University
Photo: Prof. Yoshihiro Yamazaki, Department of Physics, Waseda University

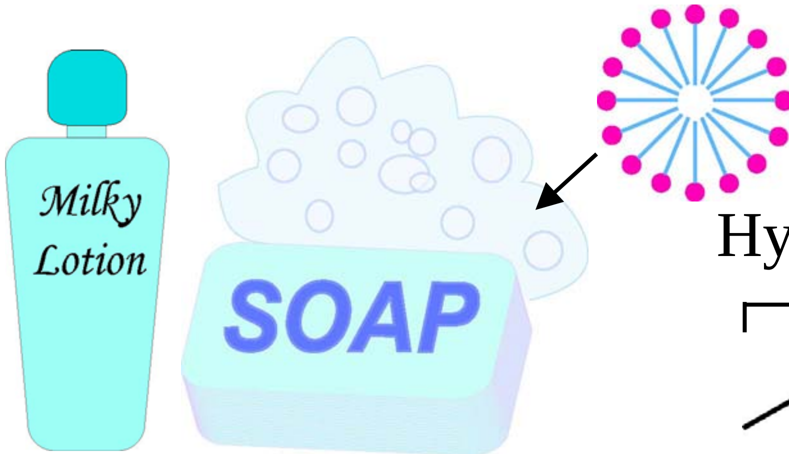
Examples of Self-organization

・Thermodynamically-non-equilibrium systems
(Sand dunes, forests, and oscillation in chemical reactions)

Forest (Mt.Shimagare, Tateshina)

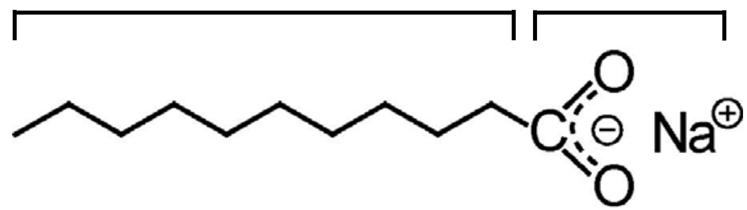
‡ PENSION RADISH–GARDEN
http://www.p-rg.com/n/nanafushigi.html

5.2 Self-organization of Amphipathic Molecules



Micelle (Soap and cosmetics)

Hydrophobicity Hydrophilicity

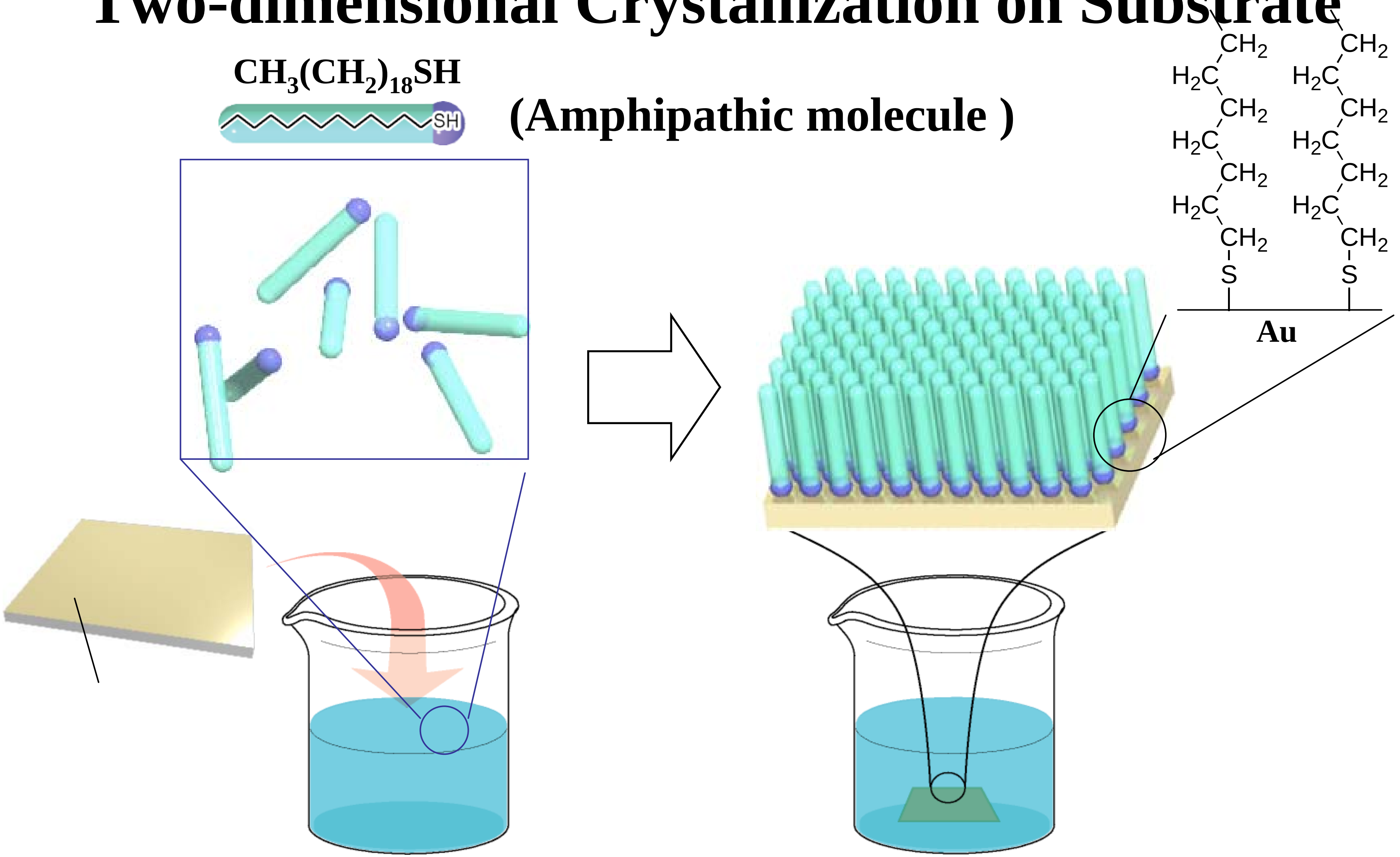


Self-organization at surface of the base

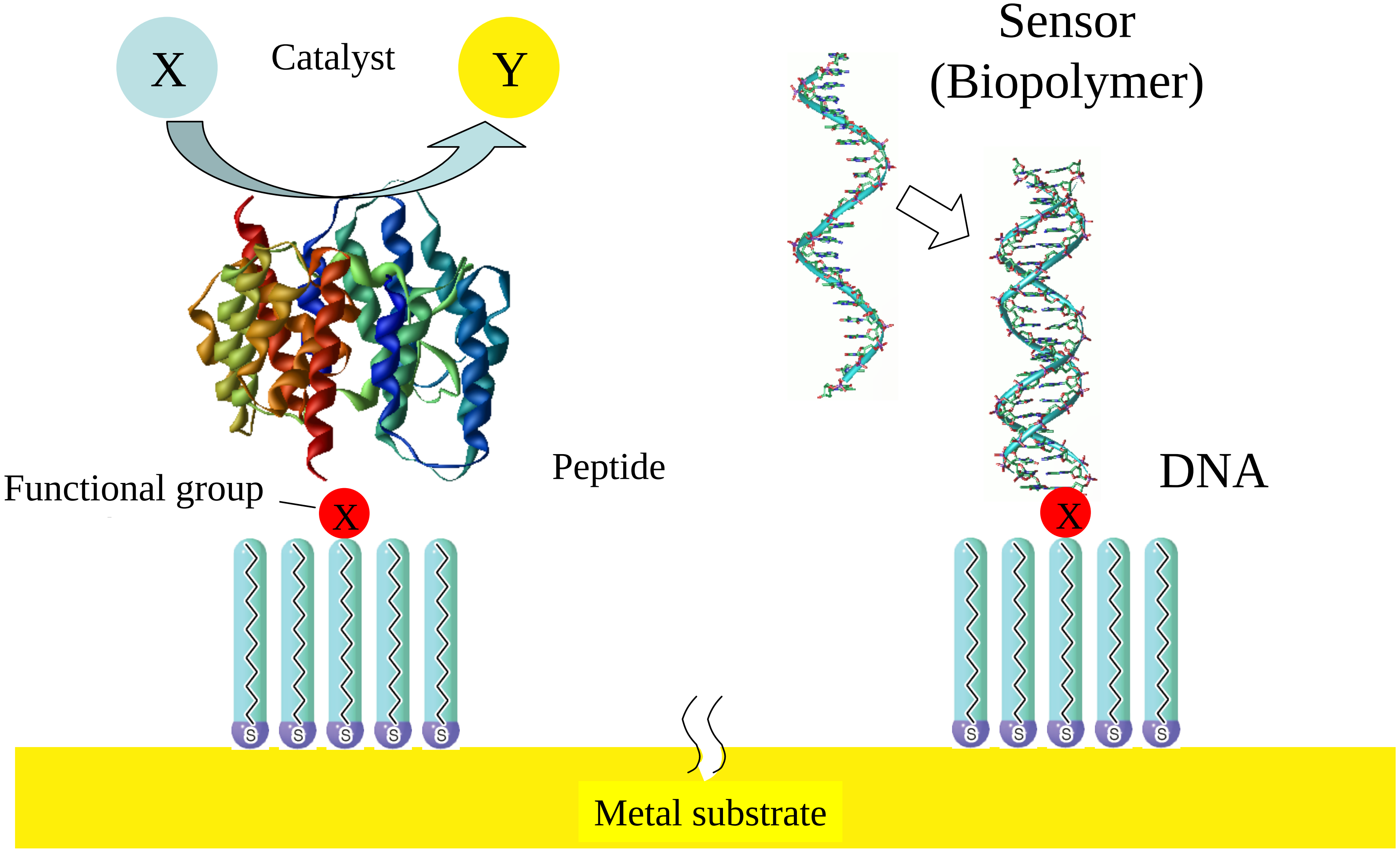
Functionalization at the molecular level
(Self-assembled monolayer)

Self-assembled Monolayer (SAM)

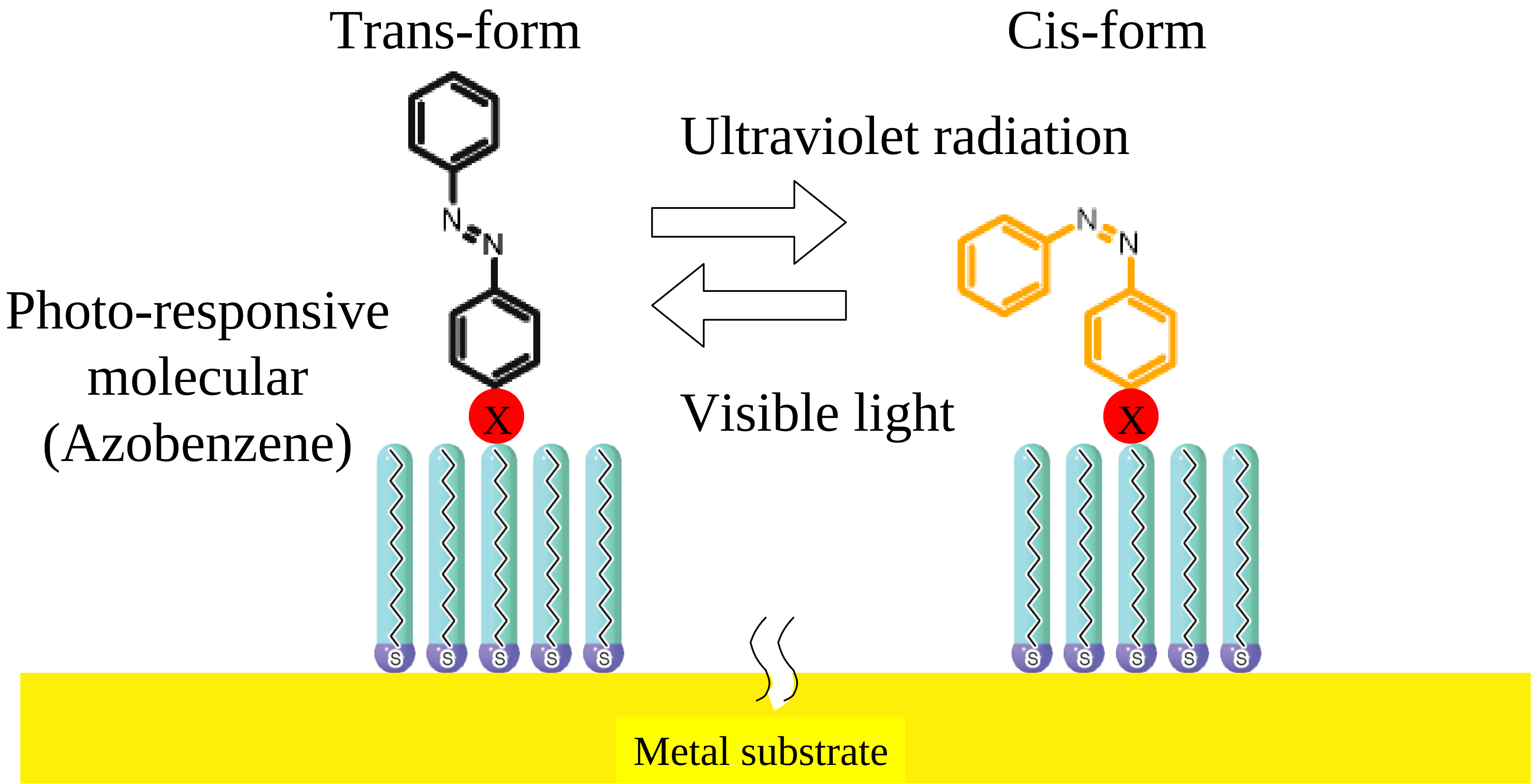
Two-dimensional Crystallization on Substrate



Application of Self-assembled Monolayer (1) (Monomolecular Catalyst and Monomolecular Sensor)



Application of Self-assembled Monolayer (2) (Optical Memory and Sensor)



Phenomenon Highlighted by Ultra-fine (1)

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Images provided by Seiko Epson Corporation

Phenomenon Highlighted by Ultra-fine (2)

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Images provided by Seiko Epson Corporation

Governed by Interfacial Tension

- Interfacial tension/ gravity

$$\frac{\sigma \times \text{Circumference}}{g\,\rho \times Volume} = \frac{\sigma}{g\,\rho\,r^2}$$

1 micron-radius water droplet can yield 10^7!

σ : Interfacial tension [N m^{-1}]

g : Gravitational acceleration [m s^{-2}]

ρ : Density [kg m^{-3}]

r : Droplet radius [m]

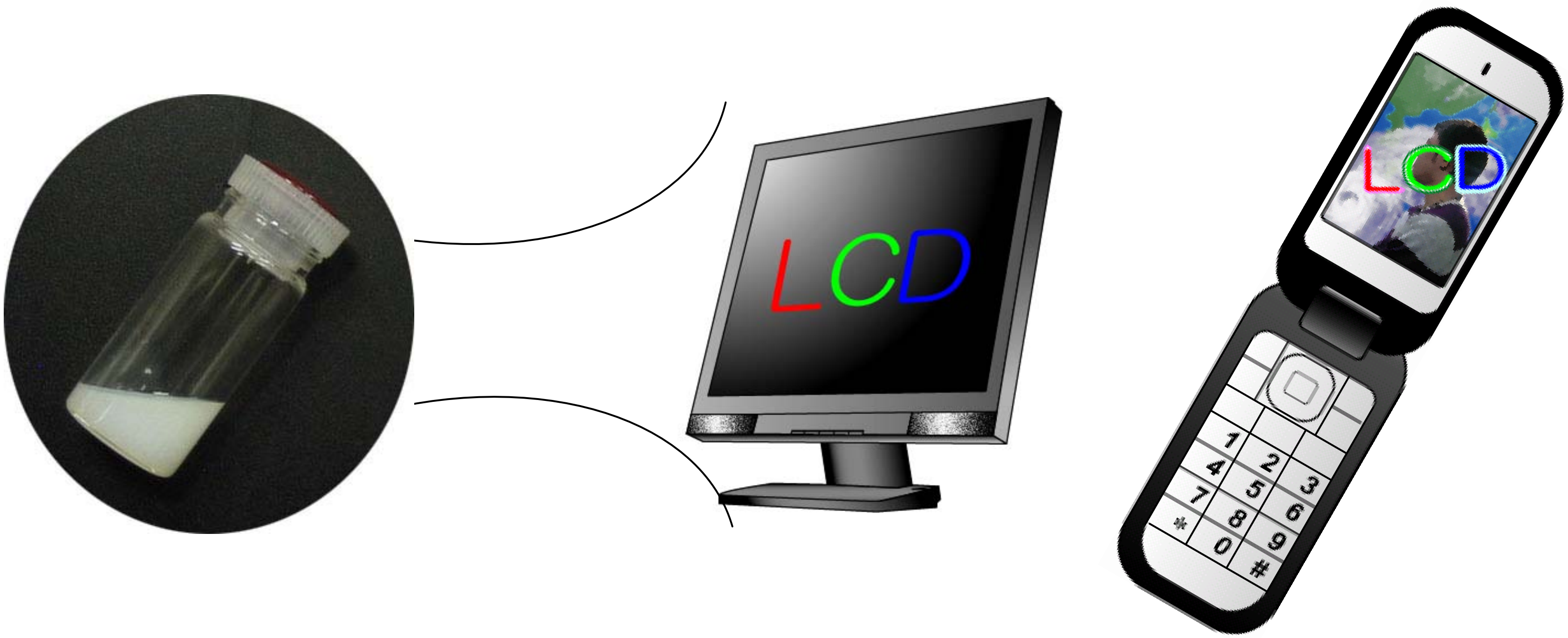
5.4 Self-assembled Soft Matter: Liquid Crystals

- The fourth state of matter

Solid, liquid crystal, liquid, and vapor

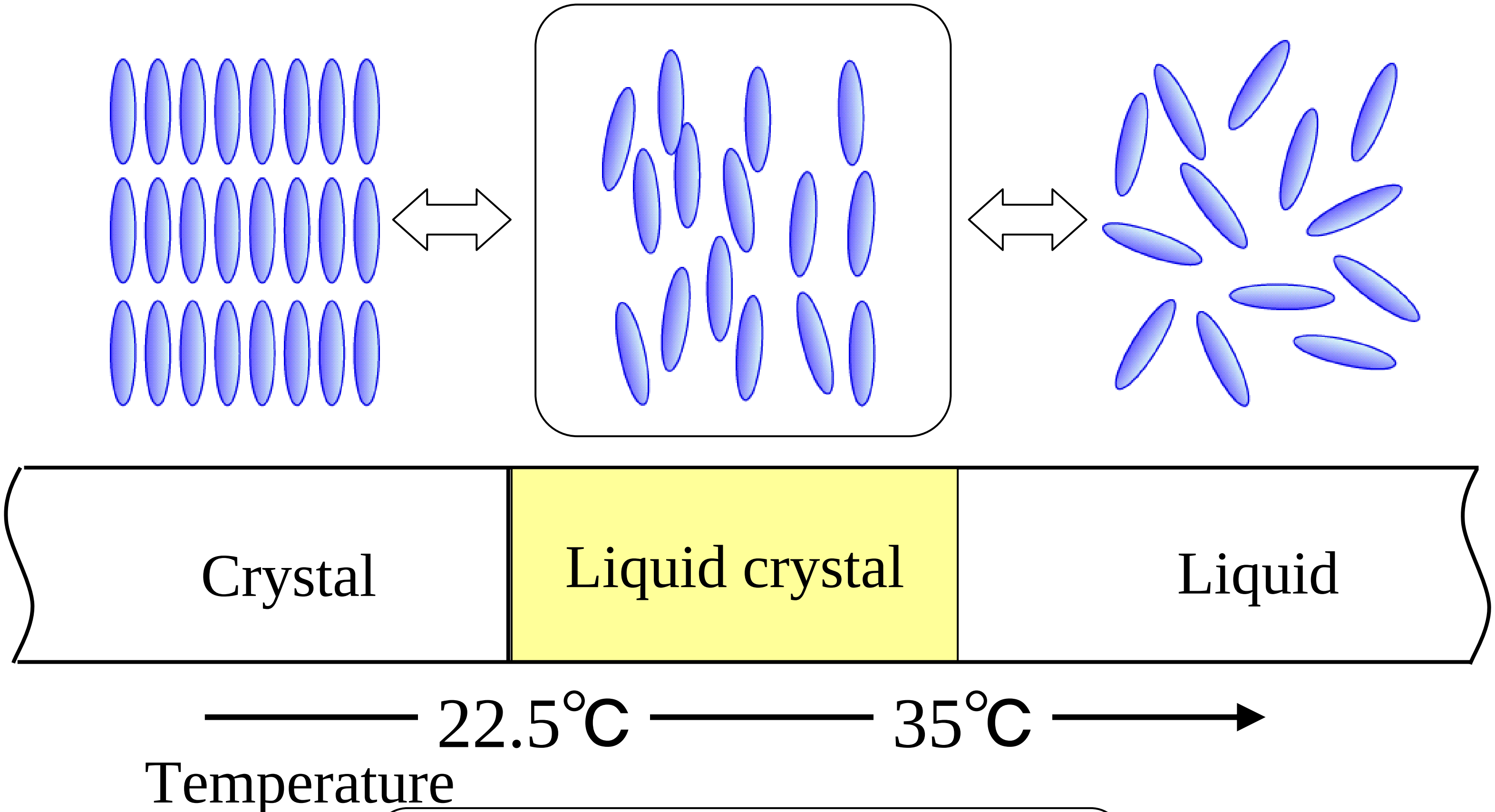
Examples of Liquid Crystal Applications

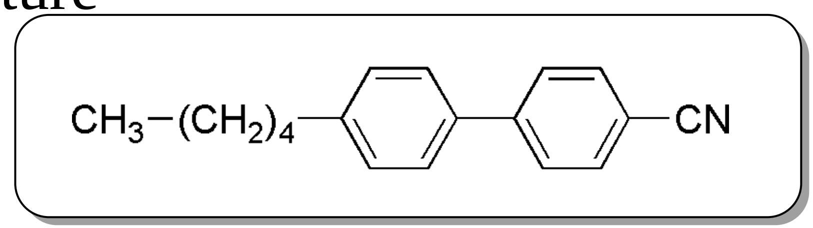
Liquid crystals are used in the displays.



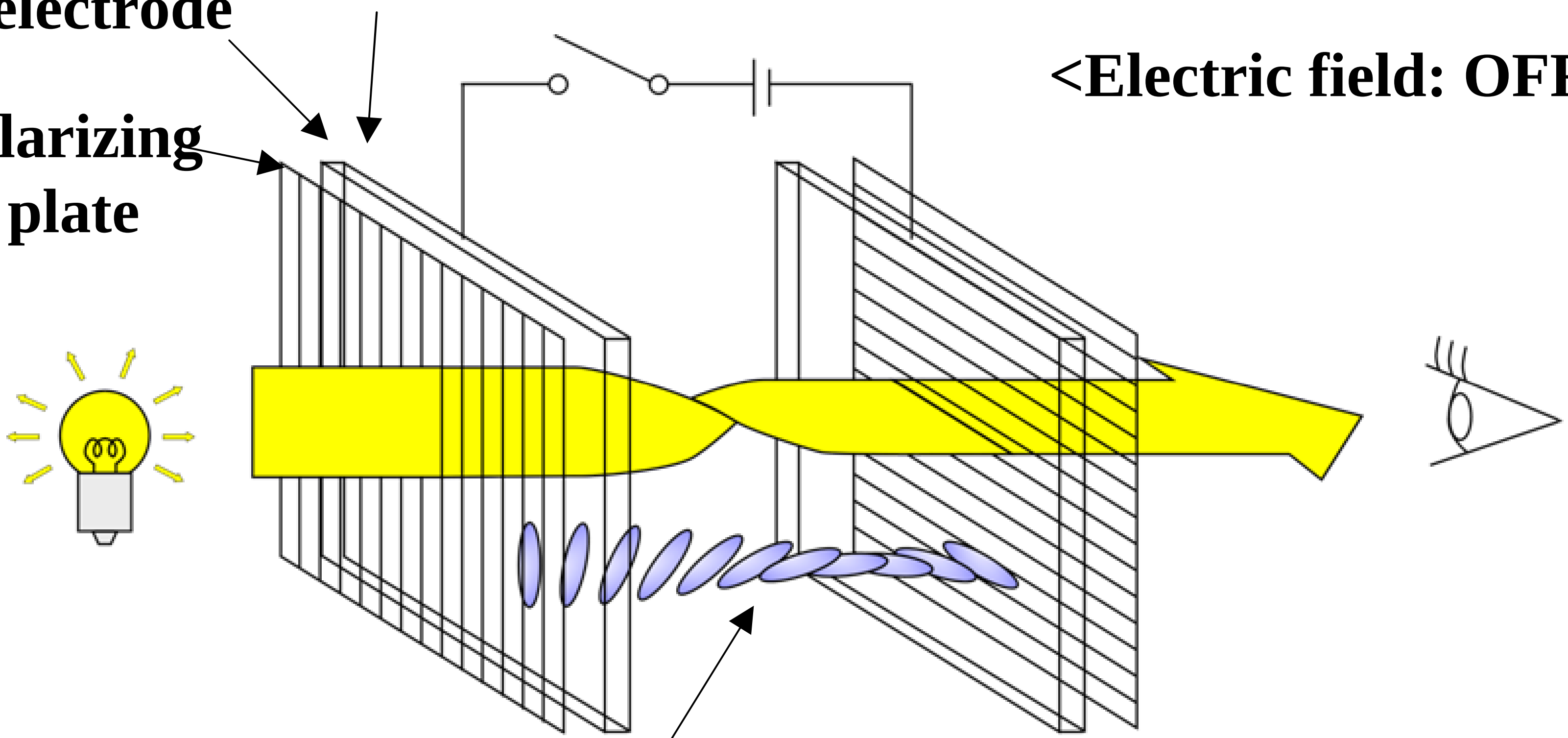
Displays for PCs and cell phones

Phase Transition of Liquid Crystals



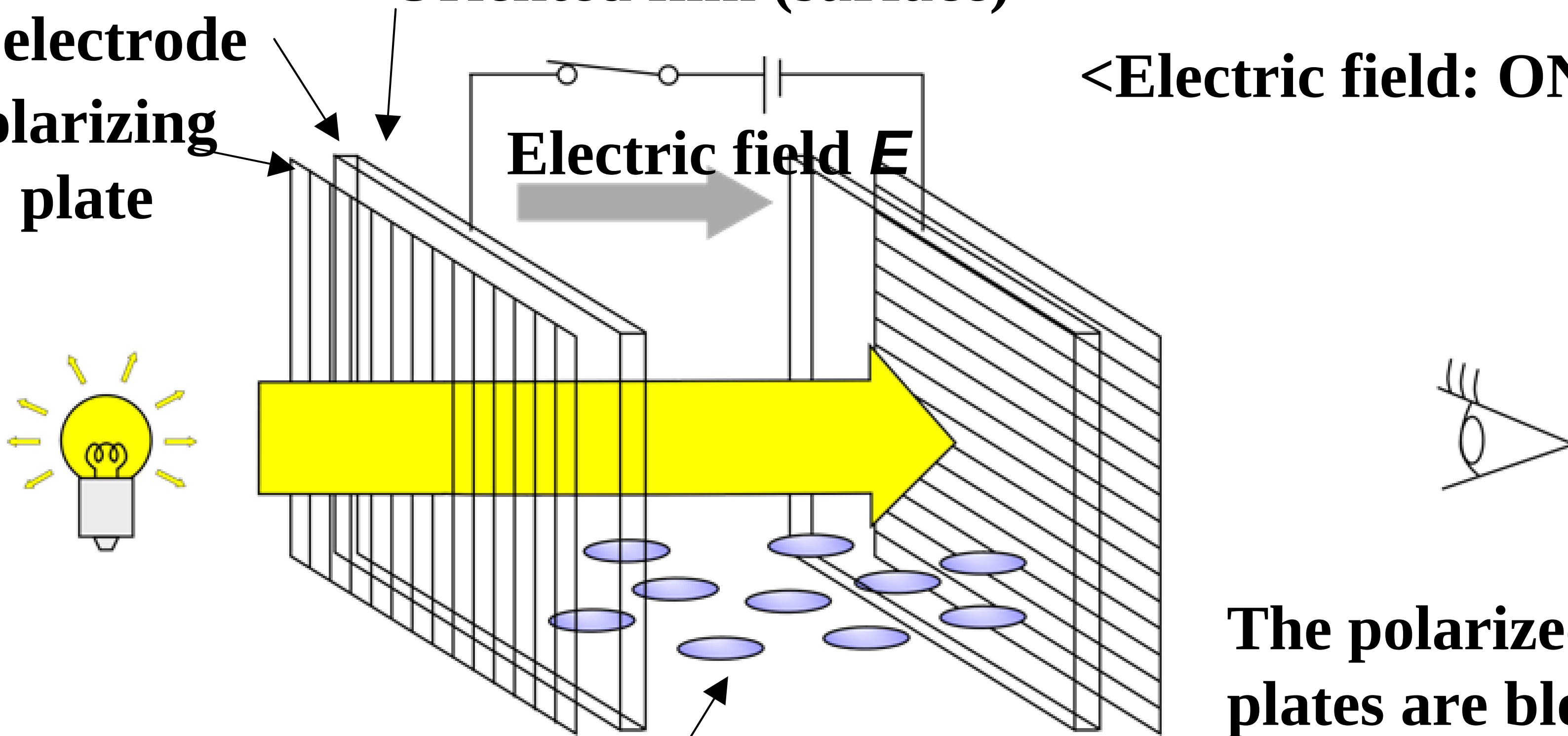


Mechanism of Liquid Crystal Displays



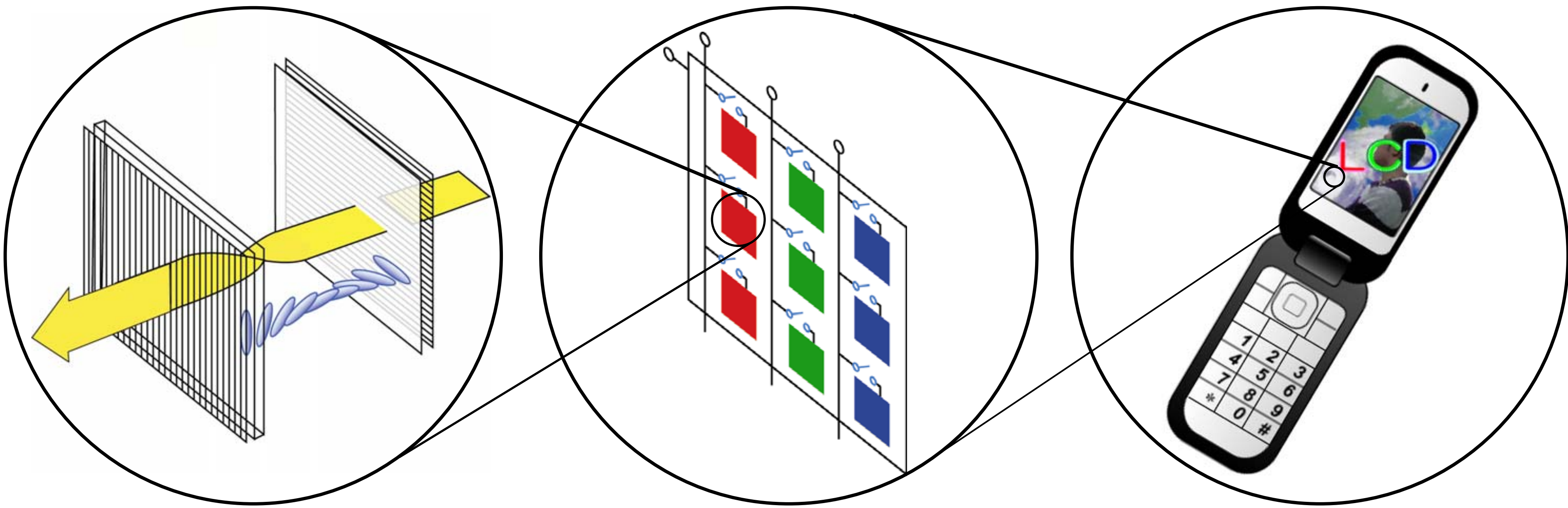
The plane of polarization will rotate due to the twisted 90˚ arrangement of liquid crystals; allowing the light to pass through.

Mechanism of Liquid Crystal Displays

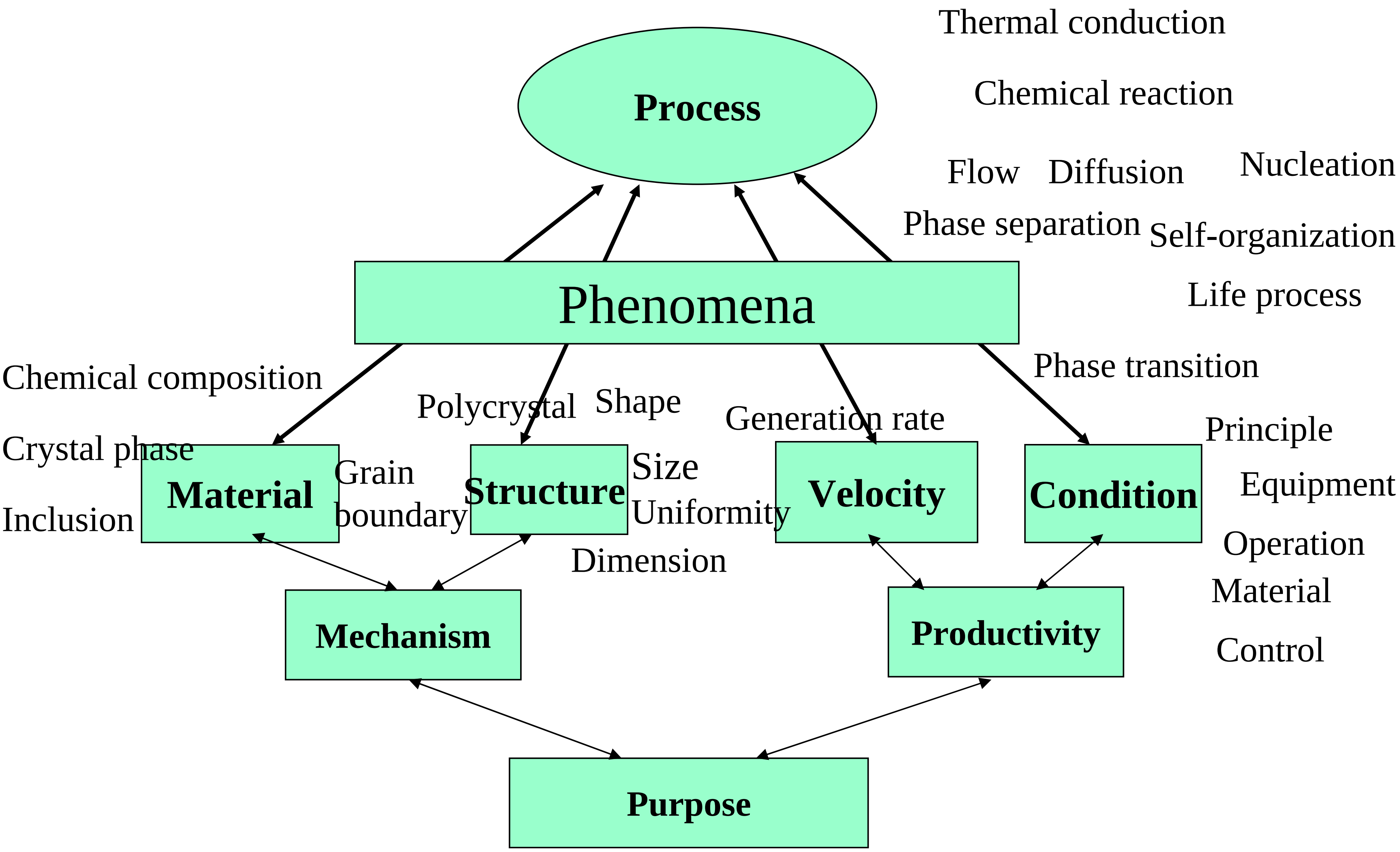


The polarized plates are blocked so the light cannot pass through –the surface appears dark.

Color Liquid Crystal Displays



Each segment is controlled by a transistor.


Thermal conduction
Chemical reaction
Process
Flow
Diffusion
Nucleation
Phase separation
Self-organization
Phenomena
Life process
Phase transition
Chemical composition
Polycrystal
Shape
Generation rate
Principle
Crystal phase
Material
Grain boundary
Structure
Size
Uniformity
Velocity
Condition
Equipment
Inclusion
Operation
Dimension
Mechanism
Productivity
Material
Control
Purpose

6. Matter, Physical Properties, Structure, Functions, and Applications For Liquid Crystal Displays:

Matter: rod-shaped and electronically-polarized molecules are weakly arranged.

Physical properties: polarization in the substance may shift the arrangement.

Structure: 10 micron films are filled in between the plane electrodes.

Functions: Alter the arrangement of molecules in response to the state of the electric field.
Change from transparent to opaque.

Applications: Displays can be achieved if every pixel is controlled.
Color displays can be obtained by enabling the polarized light to pass through a color filter.

7. The Latest Research

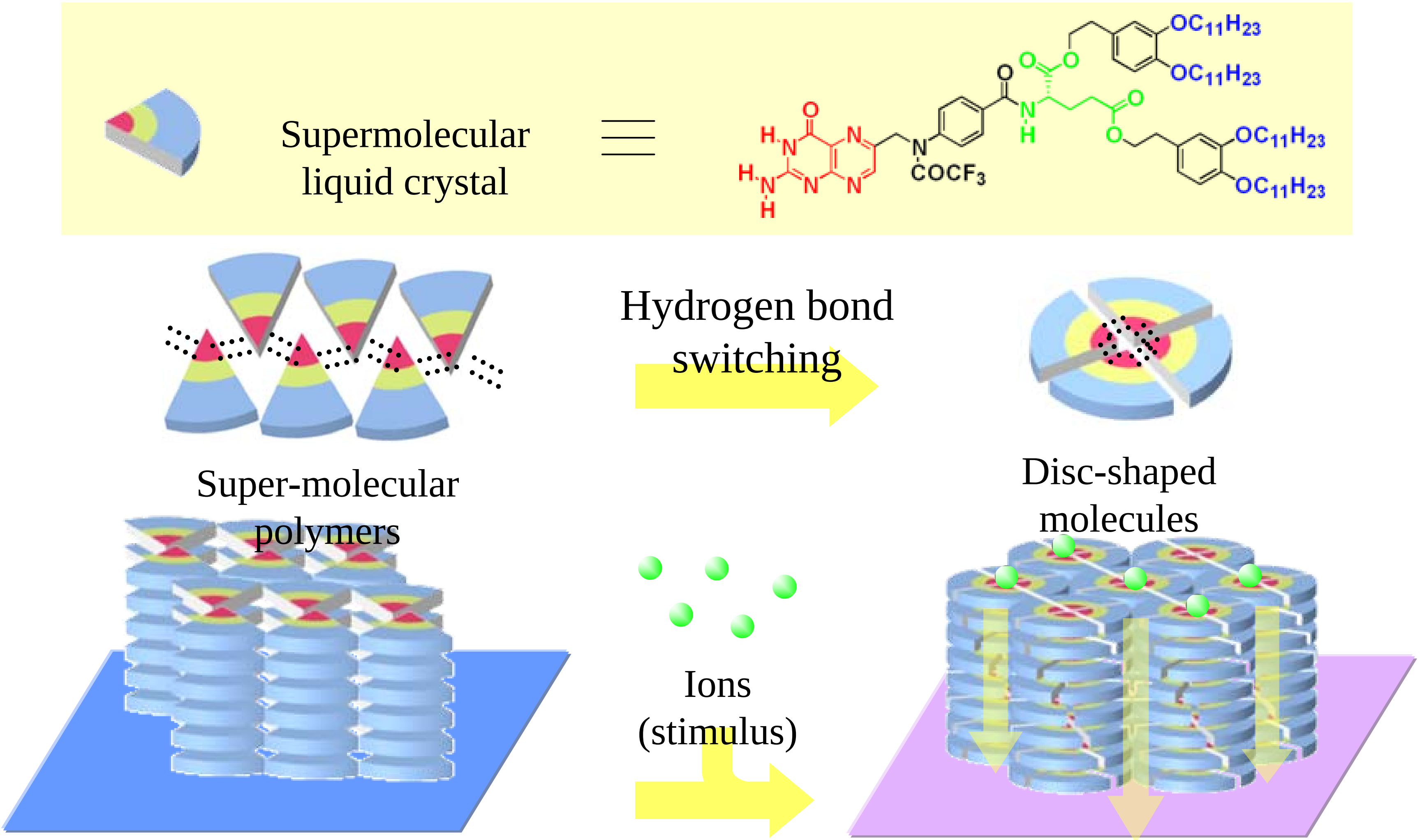
Molecular design and high-level functional expression based on the reaction design

High-level control and applications of self-organization

Multi-function integration

Replication and integration of organisms

Development of Liquid Crystal Based Ion Sensors



Self-organization structures are changed and ion signals are sent in response to the stimulus.

Kato Laboratory: Department of Chemistry and Biotechnology School of Engineering, The University of Tokyo

8. Summary of Soft Matter

Applications:

Structural materials (general-purpose plastics, high-performance plastics, general-purpose films, and fibers)

Functional materials (liquid crystals and semiconductors =electro-conductive plastics)

Matter (designs of molecules and their assembly), structure, velocity, and conditions

Functionalized by particular matter and its structure

Phenomenon (interfacial tension and Marangoni convection)

Next lecture topics: Earth-friendly durable materials (devices), fuel cells, and micro-chemical chips