Materiali Intelligenti: introduzione

Corso Materiali Intelligenti e Biomimetici

2020

Research Center E. Piaggio
University of Pisa

DIPARTIMENTO DI INGEGNERIA DELL'INFORMAZIONE

IN SUPREMÆ DIGNITATIS 1343
UNIVERSITÀ DI PISA

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Homepage corso: www.centropiaggio.unipi.it/course/materiali-intelligenti

Centro 3R
Centro Interuniversitario per la Promozione dei Principi delle 3R nella Didattica e nella Ricerca

La mia ricerca

- Modelli in vitro per le 3R
- Brain imaging – da organoidi al nostro cervello
- UBORA

Le mie ricerche biomediche
“Shaping and modelling life”

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Anno di transizione 2020

- Martedi 12.30 -14.30 Y1
- Scopo: progettazione guidata di un dispositivo per la stimolazione ed il test meccanico di tessuti biologici: i) basato su componenti classici; ii) su materiali intelligenti (differenze costi/prestazioni tra sistema classico e con smart materials)

PORTARE IL PROPRIO LAPTOP

- Giovedi 11.30-13.30 All
- Venerdi 15.30-16.30 All
- Venerdi 16.30-18.30 Y2
- Scopo: utilizzare le conoscenze acquiste al primo semestre per analizzare problemi con geometrie e cinetiche piu complesse usando metodi computazionali

Esame

All

- Scritto di 1.5 ore con domande di teoria e esercizi sui materiali intelligenti e biomimetici
- Voto 3/5

Y1

- Progettino e domande su quanto svolto nel laboratorio
- Voto 2/5

Y2

- Esercizio da svolgere usando FEM
- Voto 2/5

L'esame è superato solo se entrambe le prove sono sufficienti (>18/30).
E' possibile ripetere lo scritto mantenendo il voto della parte orale/progettino

Condivisione articoli e slides:

- Materials sul Centro Piaggio
  http://www.centropiaggio.unipi.it/course/materiali-intelligenti

Materiali intelligenti

Programmable materials

Functional materials

Advanced materials

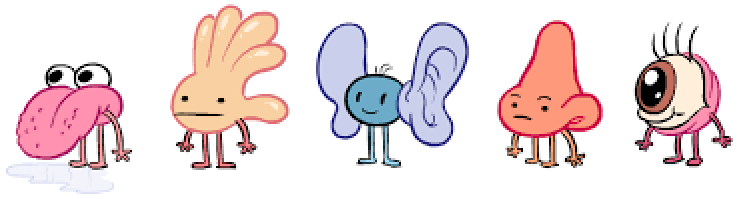
Definition of intelligence?

- Ability to perceive information, retain it as knowledge and then apply it adaptively
- Difference between intelligence and consciousness?

Definition of smart?

- Smart is synonymous with reactive, quick
- With materials the 2 words are often used interchangeably

True intelligence: bioinspired

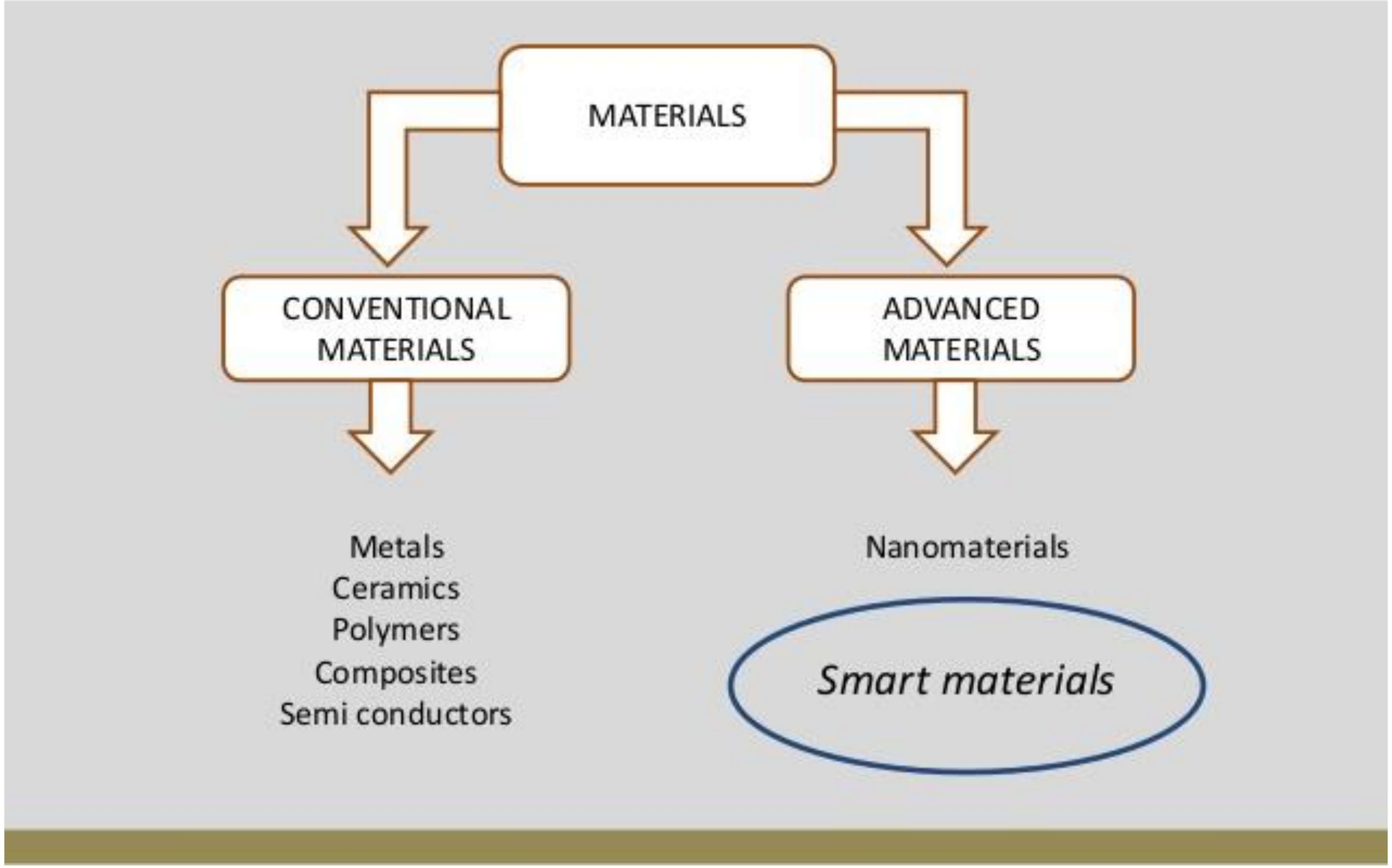


- Sense
- Signals are transferred to brain
- Brain interprets, processes signals
- The information is sent to a responder
- Responder reacts (usually actuation, ie actuates)

Intelligent Materials = Smart Materials

- Actually few materials are intelligent *per se* in the ‘true’ meaning
- So better to use other words to define them
- Smart Materials
- Programmable materials
- Functional materials
- Advanced materials

CLASSIFICATION OF MATERIALS



Smart material

- a material that has a **useful response to external stimuli**.
- The change is inherent to the material and not a result of some electronics.
- The reaction may exhibit itself as a change in volume, a change in colour or a change in viscosity-or any other material property
- In many cases this reaction is **reversible**
- Example: the coating on spectacles which reacts to the level of UV light, turning your ordinary glasses into sunglasses when you go outside and back again when you return inside. This coating is made from a smart material which is described as being photochromic.

Why do we need smart or intelligent materials?

- Human tissues or organs in the body have complicated functions and are not easy to replace with conventional artificial materials.
- Need to design and synthesize materials with better performance
- human beings are dynamic organisms.
- Stimuli-responsive materials with intelligence and drive are also dynamic.
- To achieve more sophisticated drug treatment, or to substitute biological functions, the use of smart materials is inevitable.

Desirables

- **Responsive**
- Response is **reproducible** and predictive!
- **Reversibility** is highly desirable too

- (3Rs- responsive, reproducible, reversibile)

How are they responsive? They respond to

- Light
- Heat
- Electric field
- Magnetic field
- Flow
- pH……

- These stimuli can be external or generated inside the material.

- Other stimuli….?

Applications?

- Sensing
- Actuation
- Control
- Detection (difference between sensing and detection?)
- Diagnostics
- Damage arrest
- Shock absorbers
- Etc… Many more to invent.

Vast number of responsive, predictable behaviours

Type	Input		Output
Piezoelectric	Deformation	⟺	Electric field
Pyroelectric	Temperature difference	⟺	Electric field
Thermoelectric	Temperature difference	⟺	Electric field
Electrostrictive	Electric field	⟺	Deformation
Magnetostrictive	Magnetic field	⟺	Deformation

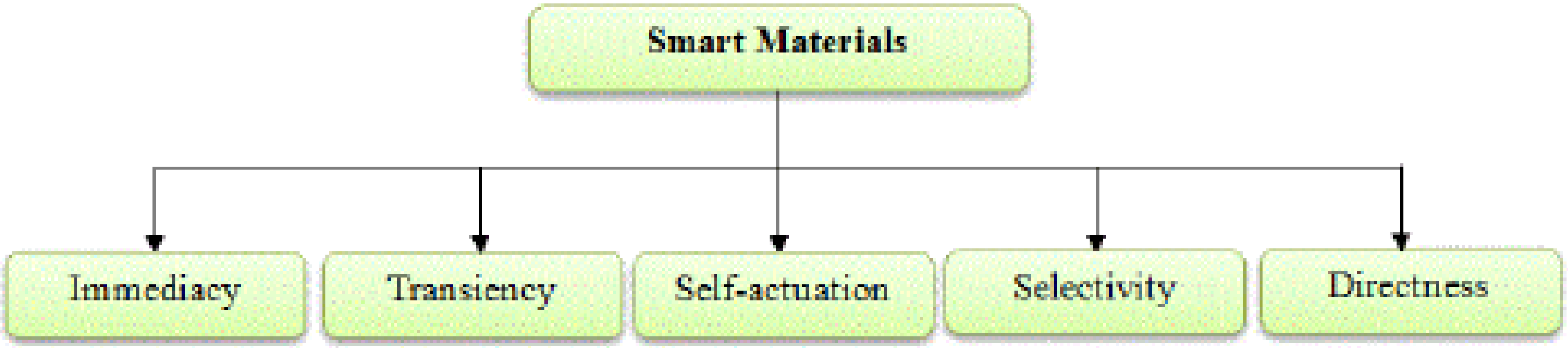
classification

- properties

- Active -actuate
- Passive- sense

Sensibile a	**Risponde con**	**Esempio**
• Luce	• Cambia colore	• Lente fotocromica
• Temperatura	• Cambia forma	• SMA

Desirable properties



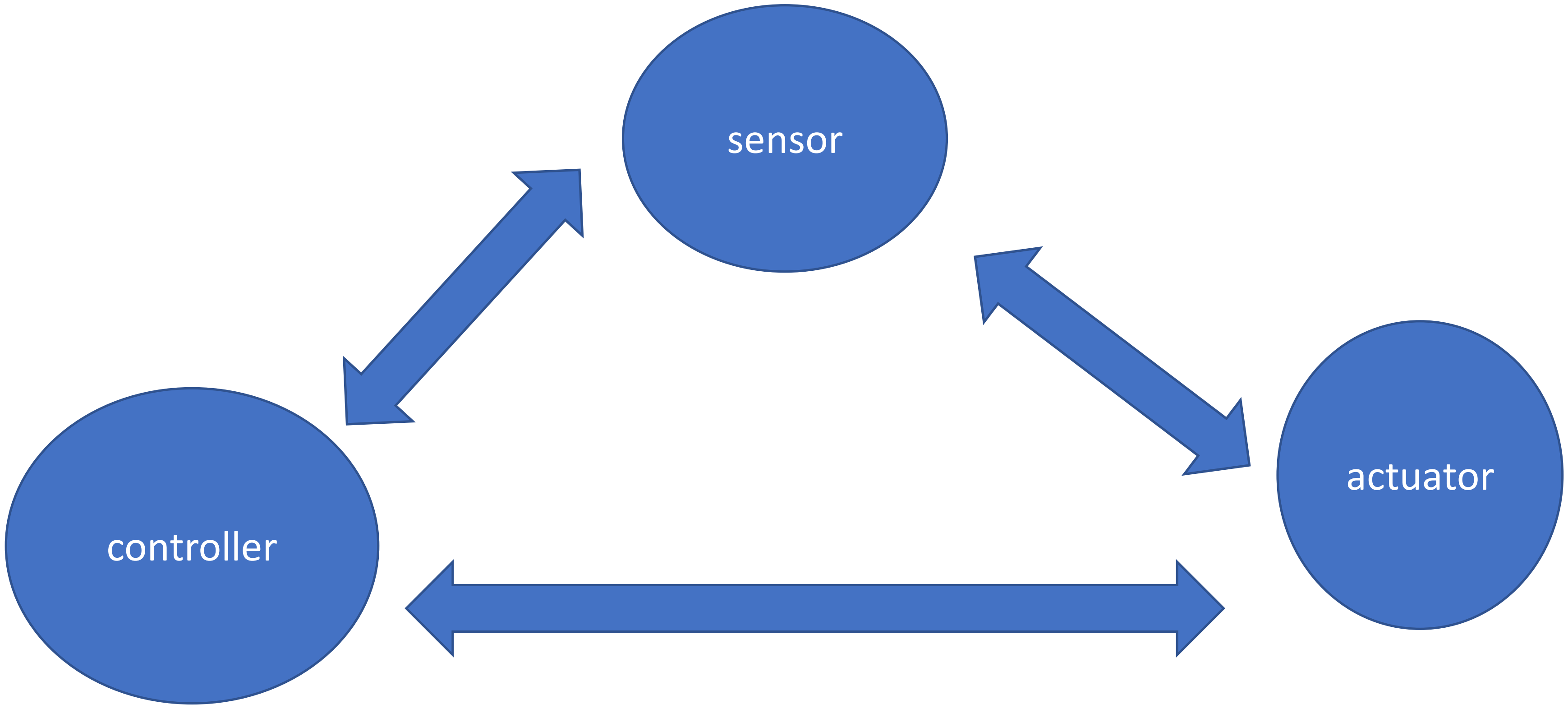
Smart materials vs. Smart structures

distinction between a smart material and a smart structure should be emphasized:

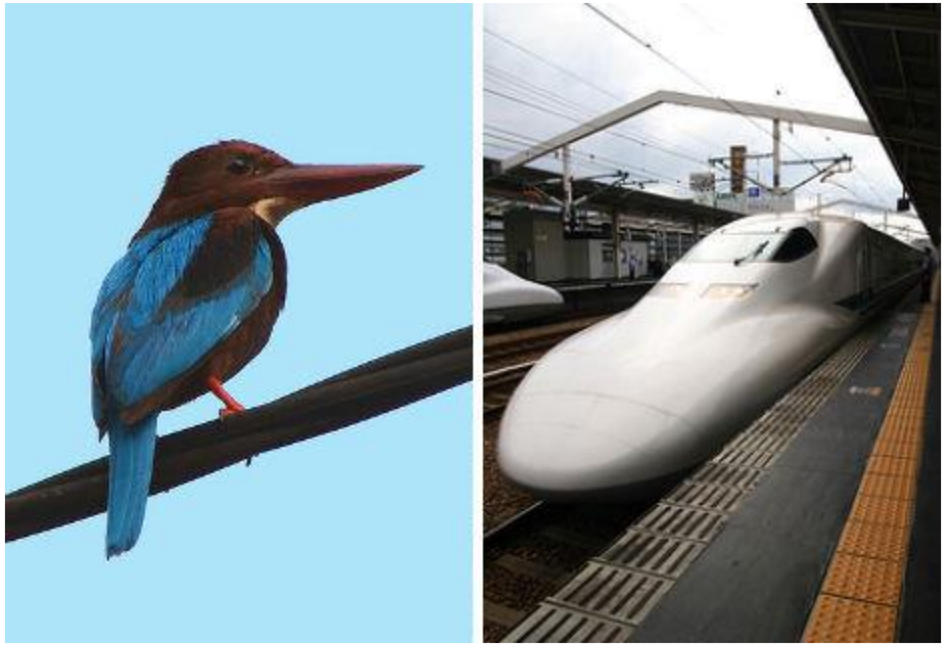
A **smart structure** incorporates some form of actuator and sensor (which may be made from smart materials) with control hardware and software to form a system which reacts to its environment.

A **smart material** reacts to the environments by itself.

Smart system or structure

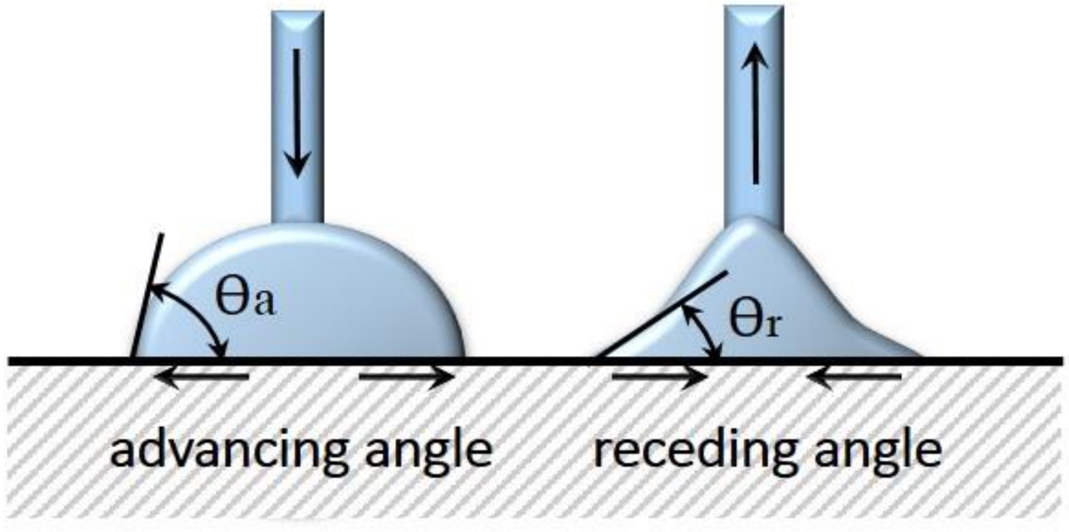


Bioinspired materials and systems

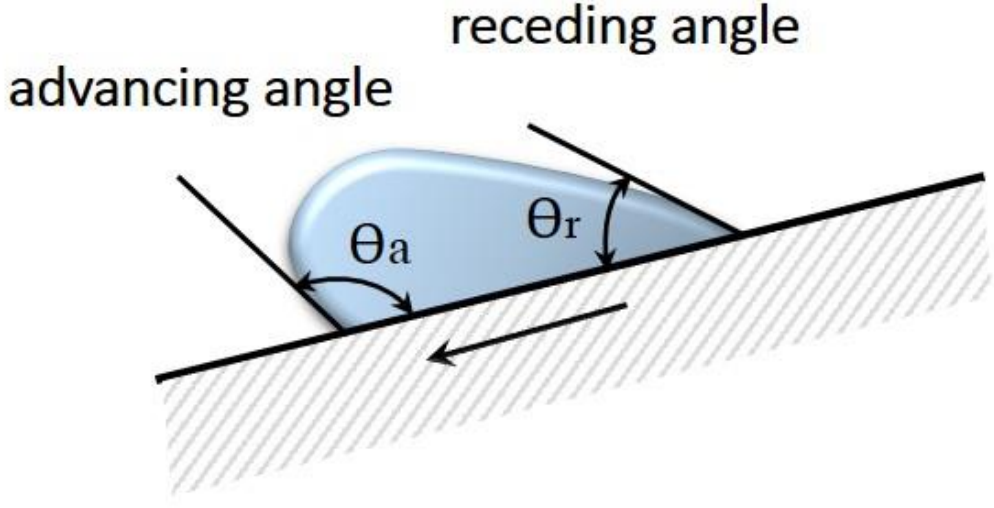


Superhydrophobicity and hydrophilicity: sistemi che minimizzano l’energia superficale

Angolo di avanzamento e recessione.



volume changing method



tilting cradle

Tilt angle, angolo di inclinazione a cui la goccia muove. (se e’ <10° la superficie e’ superhydrophobic e auto pulente perche’ la goccia cadde subito portando con se particolato)
Contact angle hysteresis (CAH) =angolo di avanzamento-angolo di recessione

- **Nano-structured surfaces can have peculiar wetting properties**

→ Interplay of chemistry and nano-topography: **superhydrophobic effect**

→ Superhydrophobicity is found in **Nature** (Lotus Effect®)

→ Scientists are **engineering materials to be superhydrophobic** and require less cleaning

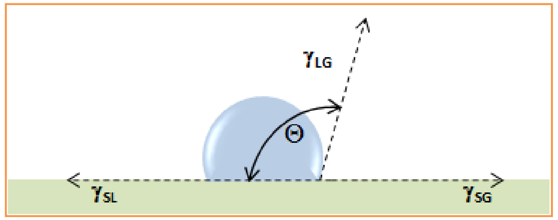
→ **Applications**

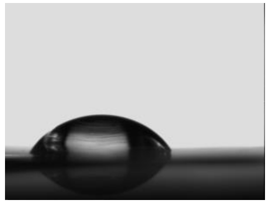
- Solar panels
- Textiles
- Coatings

- Surfaces can be classified depending on their contact angle as illustrated in the Table.

- Contact angle is a measurement of *the interaction energy between the surface and the liquid*.

Contact angle value	Type of surface	Example
~0	Super-hydrophilic	UV irradiated TiO_2
> 30	Hydrophilic	Glass
30-90	Intermediate*	Aluminium
90-140	Hydrophobic	Plastic
140+	Superhydrophobic	Lotus leaf





- There are some **natural materials** that have superhydrophobic properties, such as the **Lotus** leaf, and the legs of the **water strider**

- Another plant that has superhydrophobic leaves is **Nasturtium**

→ Detailed **SEM analysis** of leaves that display the Lotus-effect has revealed the presence of **wax nanocrystals** on the leaf surface.

→ These crystals provide a water-repellent layer, which is enhanced by the roughness of the surface, making it a superhydrophobic surface, with a contact angle of about 150.

→ Water droplets interfacing with the leaf are in contact with a **large fraction of air**. The image below shows the progressive magnification of a Nasturium leaf.

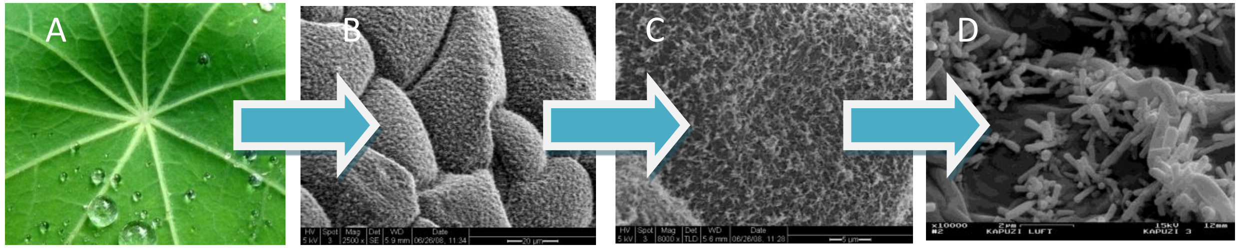
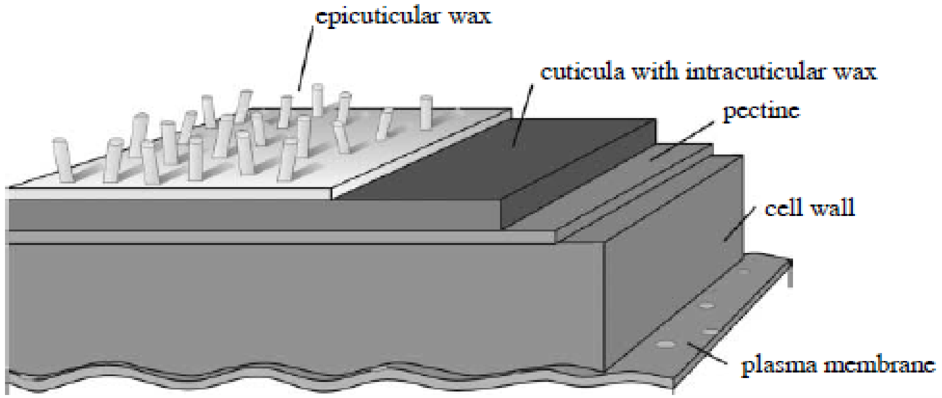
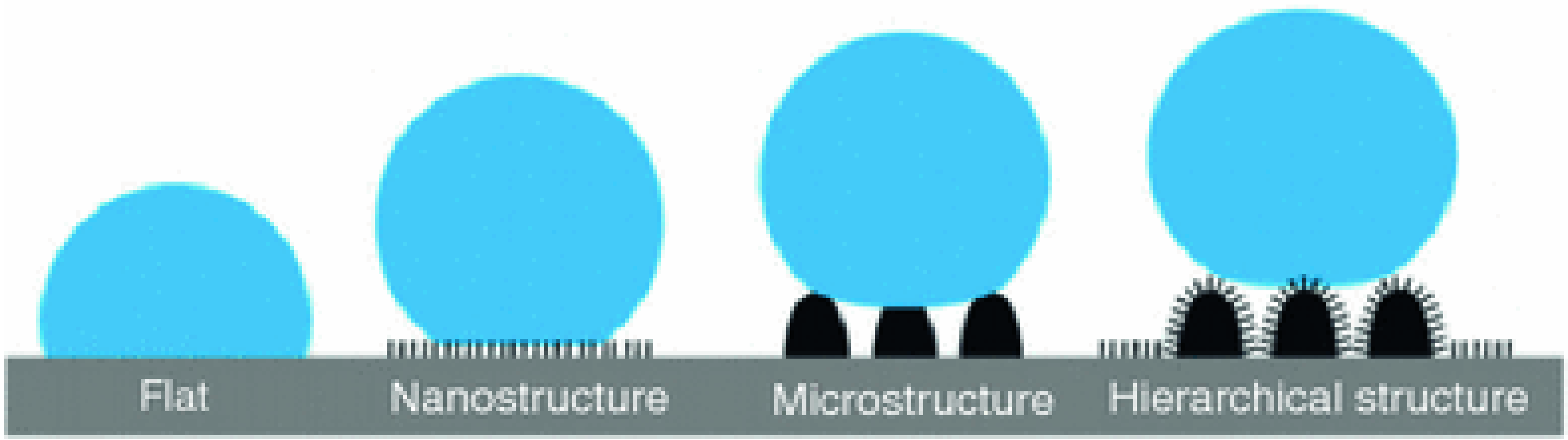


Figure 1. Micro and nanostructure of a nasturtium leaf (Image credits: see slide 16)


epicuticular wax
cuticula with intracuticular wax
pectine
cell wall
plasma membrane


Flat
Nanostructure
Microstructure
Hierarchical structure

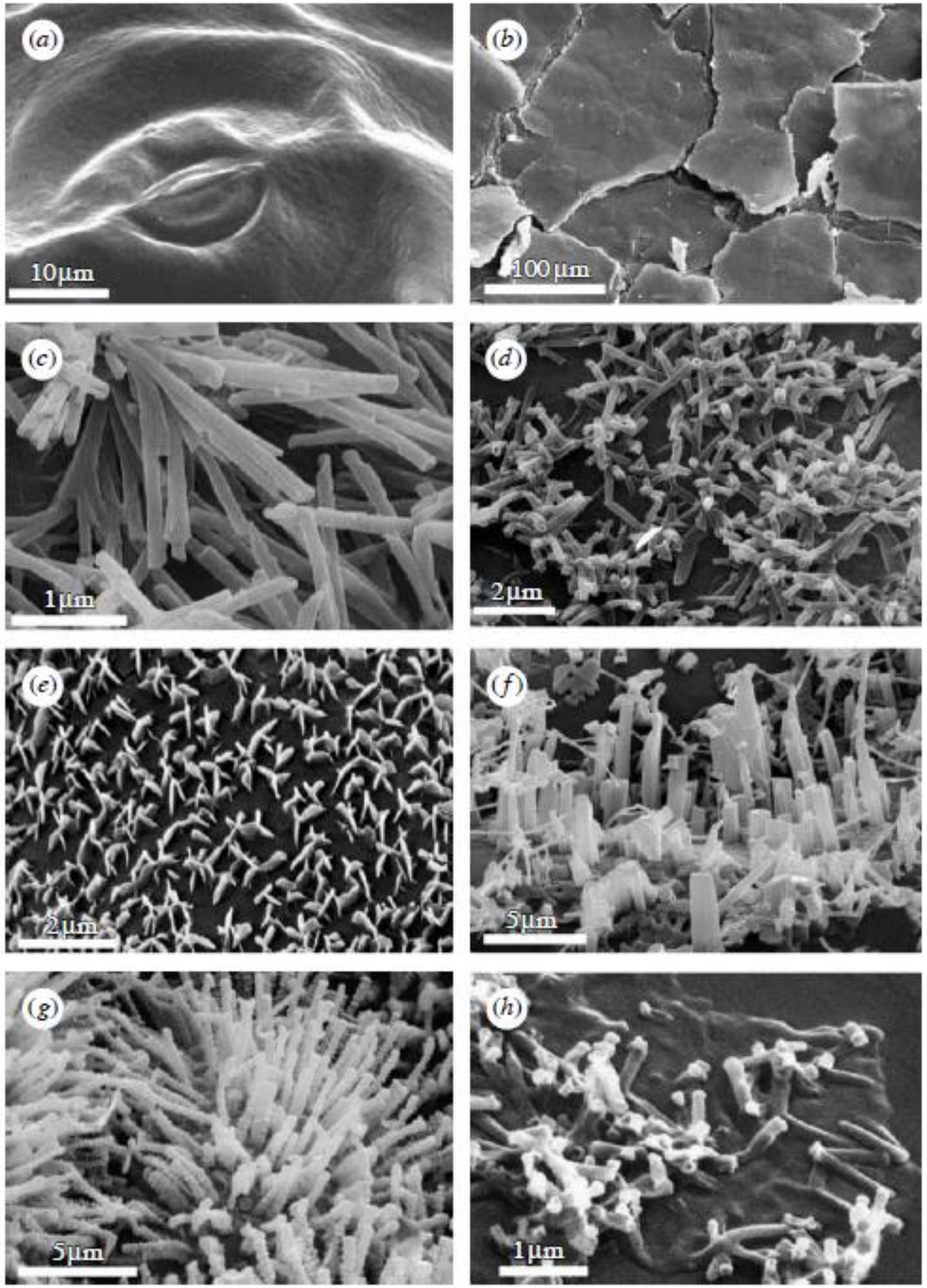


Figure 2. SEM micrographs of cell surface structuring by epicuticular waxes. (*a*) Thin wax films, hardly visible in SEM, cover many plant surfaces as indicated here in *H. bonariensis*. (*b*) A wax crust with fissures on a leaf of *Crassula ovate*, (*c*) β-diketone wax tubules of *E. gunnii* and (*d*) nonacosan-ol tubules on *Thalictrum flavum glaucum* leaves are shown. (*e*) Wax platelets on *Robinia pseudoacacia* leaves are arranged in rosettes. The waxes shown are (*f*) simple rodlets on a leaf of *Brassica oleracea*, whereas the rodlets shown are (*g*) transversely ridged rodlets on a leaf of *Sassafras albidum*. (*h*) Mechanically isolated waxes from a leaf of *Thalictrum flavum* on a glass surface show wax tubules and the underlying wax film.

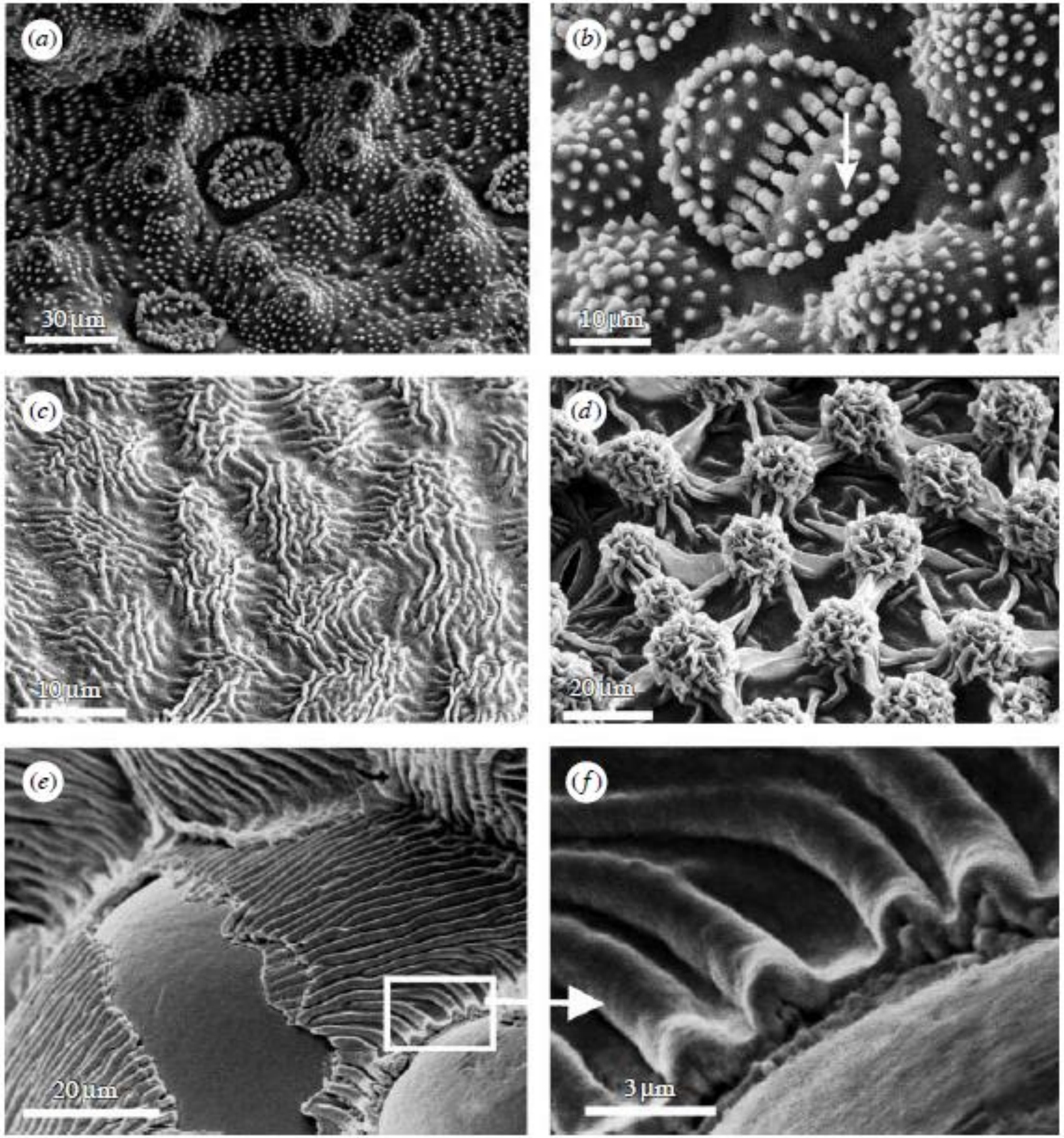


Figure 3. SEM micrographs of cell surface structuring by subcuticular insertions and cuticle folding. (*a*,*b*) The cell surface roughness of the common horsetail, *Equisetum arvensis*, is induced by subcuticular Si-ox inserts (arrow in (*b*)). (*c*) In the leaves of *Schismatoglottis neoguinensis*, the structure of the cell surface is caused by cuticle folding. Here, an irregular cuticular folding is shown, which is restricted to the central field of the cells. (*d*) In *Alocasia macrorhiza*, the cells are flat (tabular), and the cuticle in the central field forms node-like exposed structures (lower leaf side is shown). (*e*,*f*) In *Aztekium ritteri*, a part of the cuticle has been removed to show that surface structuring is induced by the cuticle and not by the underlying cell wall (*f*) shown in detail.

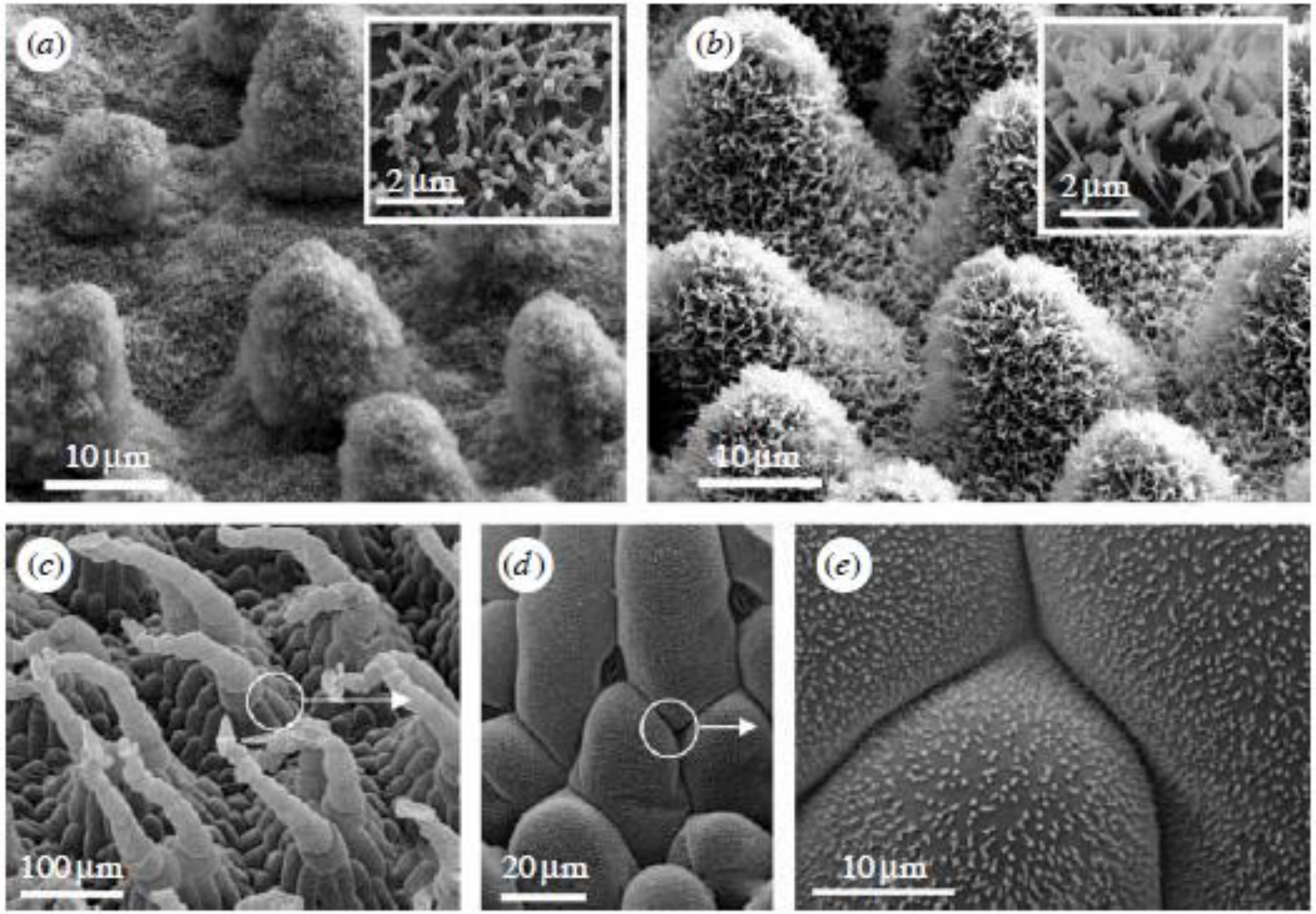
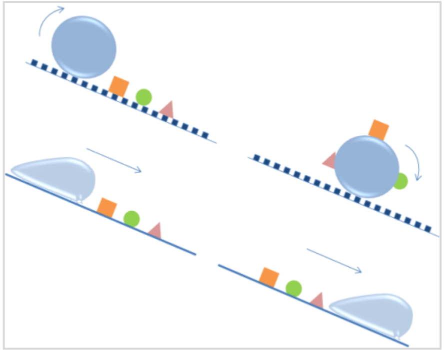


Figure 7. SEM micrographs of two kinds of hierarchical structures in plants. (*a*) The lotus and (*b*) *Euphorbia myrsinites* leaves are representative examples for the hierarchical structures composed of convex (papillose) cells with superimposed nanostructure forming wax crystals. The waxes shown in the inserts are tubules (lotus) and platelets (*Euphorbia*). (*c*–*e*) The SEM micrographs show the hierarchical structure of *Salvinia oblongifolia* hairs, composed of the multicellular hair with small rodlet-like wax crystals on top.

Self-cleaning: how does it work?

→Water droplets **roll off the leaf surface (due to air under which is compressed) and in doing so it drag dirt away from it**. This effect, called “self-cleaning” renders the Lotus leaf clean and resistant to dirt.

→ Contaminants on the surface **rest on the tips** of the rough surface. When a water droplet rolls over the contaminant, the **droplet removes the particle** from the surface of the leaf.



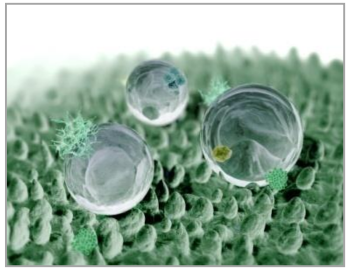
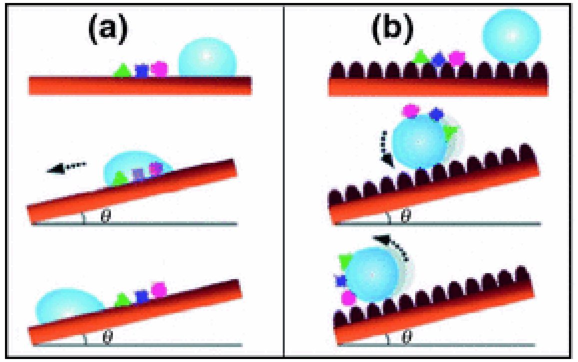


Figure 2. (Top) Diagram summarising the connection between roughening and self-cleaning: in the top image a droplet of water removes dirt from a surface thanks to the Lotus effect (bottom): Graphical representation of contaminants and water droplets on a lotus leaf (Image credits: see slide 16)



Per superfici super-idrofobici con CAH bassa si ha una superficie auto-pulente.
Porta via le particelle perche non sono aderite bene e ‘preferiscono’ la goccia di acqua

Lotus-inspired innovative materials

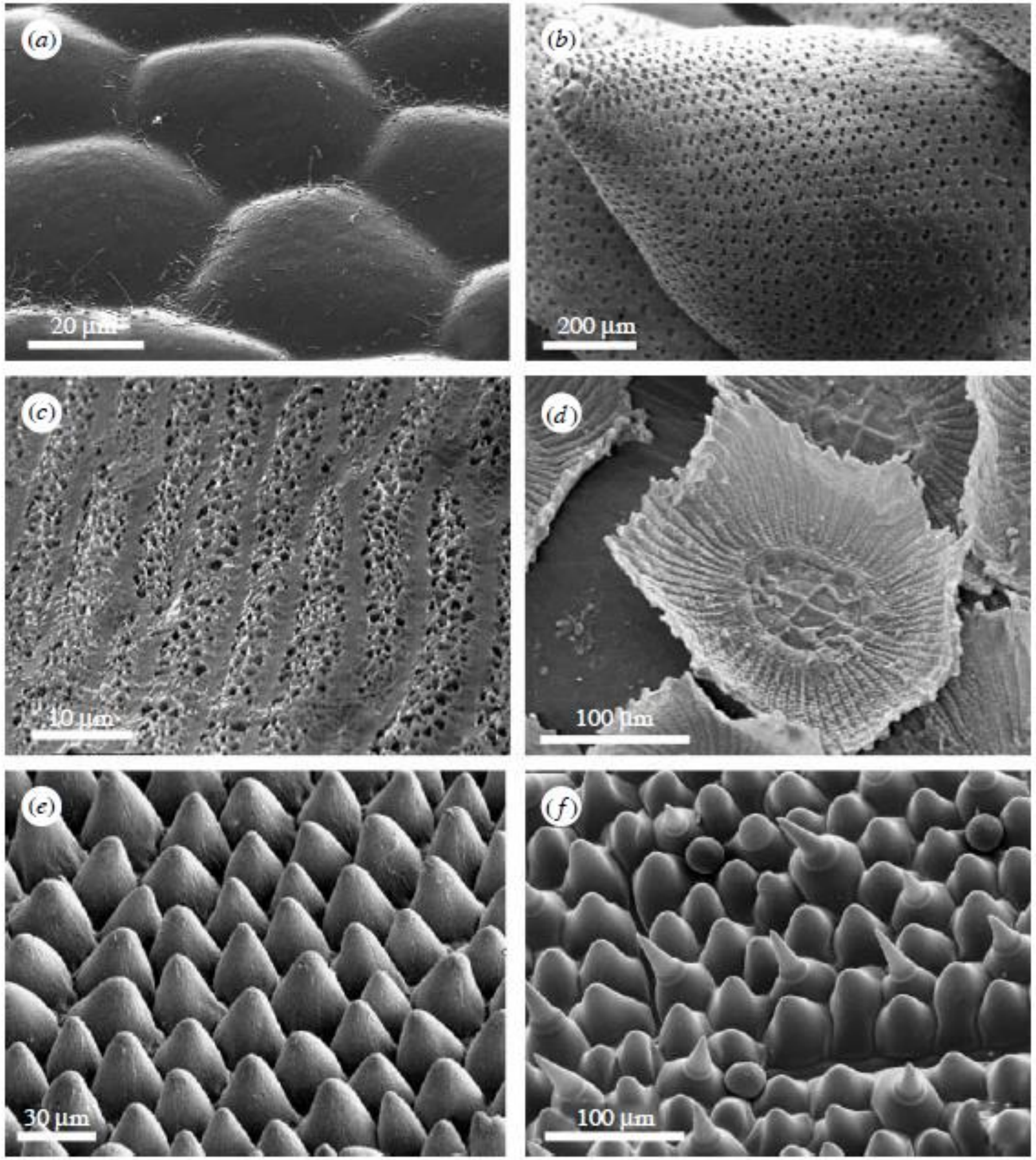
→ The Lotus effect has been an **inspiration for several superhydrophobic innovative materials**, such as paints, coatings, and textiles.

→ Some applications are:

- **Environmentally friendly coatings and textiles** that are dirt repellent and **require less cleaning** (façade paints, textiles, sanitary coatings etc.).

- **Improving the performance of solar cells (energy application)**. One of the problems with this technology is that they are kept outdoors and therefore prone to become very dirt. This **layer of dirt "masks" the catalytic areas** of the solar cells and therefore reduces its efficiency and life-time. Coating the solar panel with a superhydrophobic coating keeps the panel considerably cleaner. Because of the nano-surface roughness, the coating is transparent to UV light, a necessity for these types of devices. The superhydrophobic coating is also durable, which further improves the solar panel life-time.

Anti urine walls

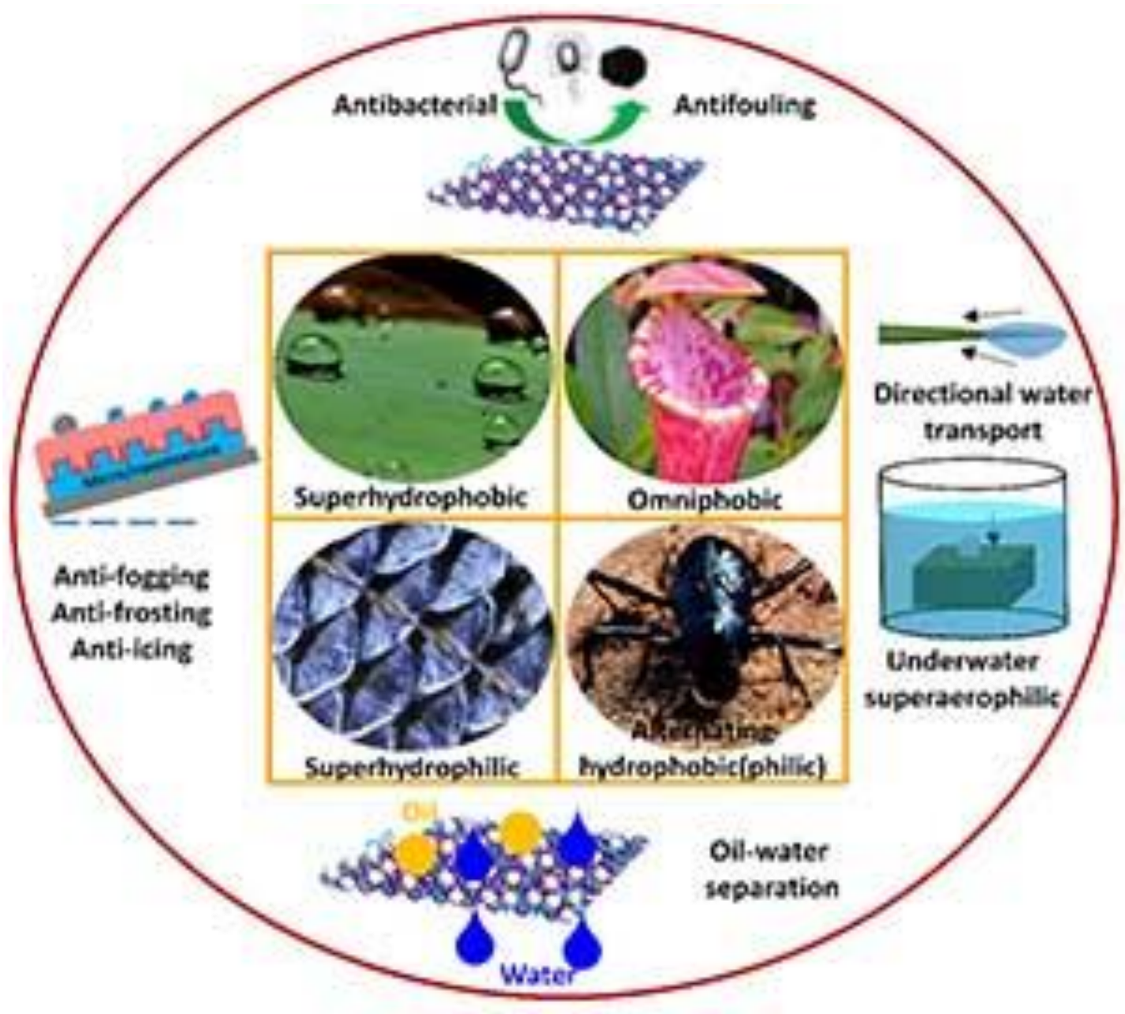


SUPER HYDROPHILIC

Figure 8. SEM micrographs of superhydrophilic plant surfaces. (*a*) The flat and unstructured surface of the water plant (*Anubias barteri*) is shown. (*b*) The surface of a water-adsorbing moss (*Sphagnum squarrosum*) is shown. In this, the pores are formed by dead and collapsed cells. (*c*) The water-adsorbing porous cell structure of the epidermis of moss *Rhacocarpus purpurescens* is shown. (*d*) The epiphytic growing Spanish moss (*Tillandsia usneoides*) with its characteristic multicellular water-absorbing hairs is shown. (*e*) The uniform conical cells on a leaf of *Calathea zebrina* and (*f*) the composition of different cell types of the superhydrophilic leaves of *Ruellia devosiana* are shown.

Applications

- Defog glass
- Clean glass and lenses
- Mirrors
- Buildings
- Anti frost, anti ice
- Anti bacteria



Domande

- Definire super-idrofobico
- Definire super-idrofilico
- Definire self cleaning
- Come sono fatte le superfici super-idrofobico?
- Come sono fatte le superfici super-idrofilico?

Paper of the week

- https://www.dropbox.com/s/p2nxdd5209m7d3z/Kreigman-PNAS-a%20scalablepipeline.pdf?dl=0

- https://bit.ly/2voDtGT