仿生界面材料：大自然粘附奥秘

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3.8 Billion Years of R&D
10-30 Million Species
Well-Adapted Solutions

仿生源头

- 蜘蛛丝的强韧性；
- 蜻蜓出色的飞行本领；
- 苍蝇的多种特殊功能；
- 孔雀、蝴蝶美丽的翅膀；
- 夜间活动型蛾（Night Moth）的眼
- 蜂巢奇妙的构造；
- 蟑螂灵敏的感知能力；
- 啄木鸟的脑壳有最紧密组织的抗震骨骼；
- 蜂鸟飞行600哩旅程耗费不到十分之一盎司的能量；
- 荷花叶面有绝佳的抗污性 (self-cleaning properties)和拨水性 (water repellent)；
- 生物的骨骼构造比钢铁强硬；
- ……

How does life make thing?

How does life make thing?

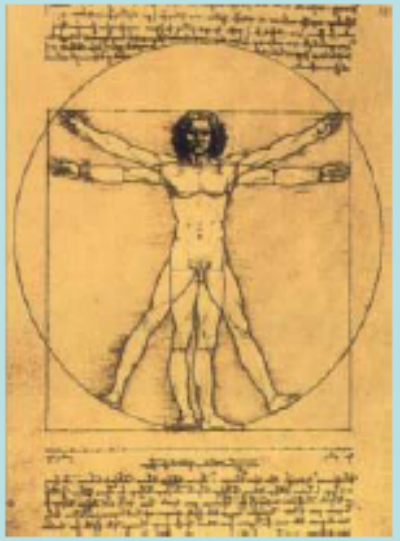
天竺葵花粉

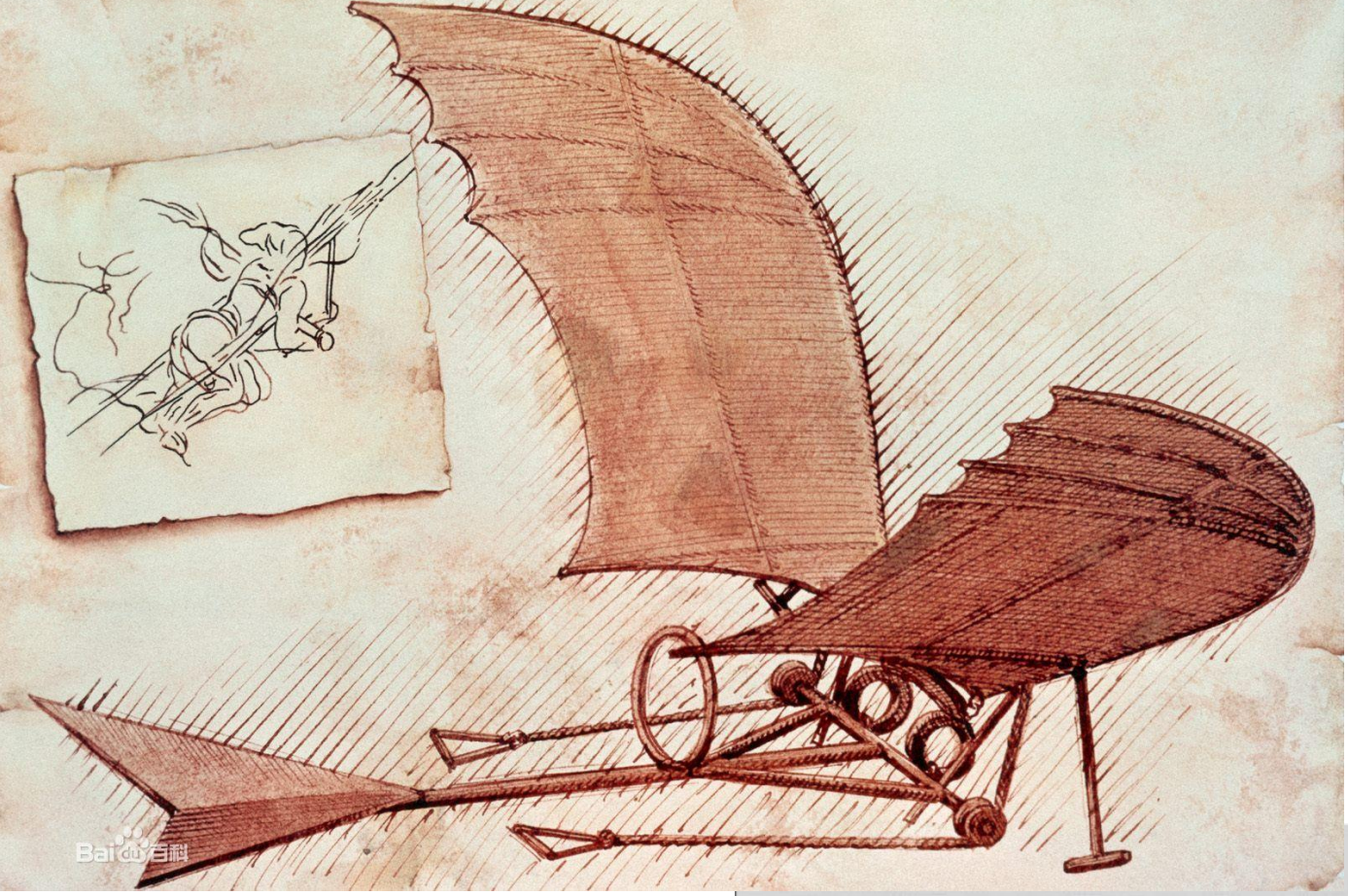
蒲公英

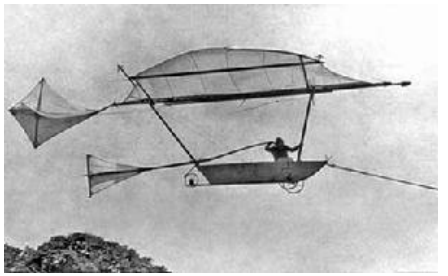
By adding Information to Matter

仿生之父——*Leonardo da Vinci*

As wrote in 16th century,
"Human ingenuity may make various inventions, but it will never devise any inventions more beautiful, nor more simple, nor more to the purpose than Nature does; because in her inventions nothing is wanting and nothing is superfluous".



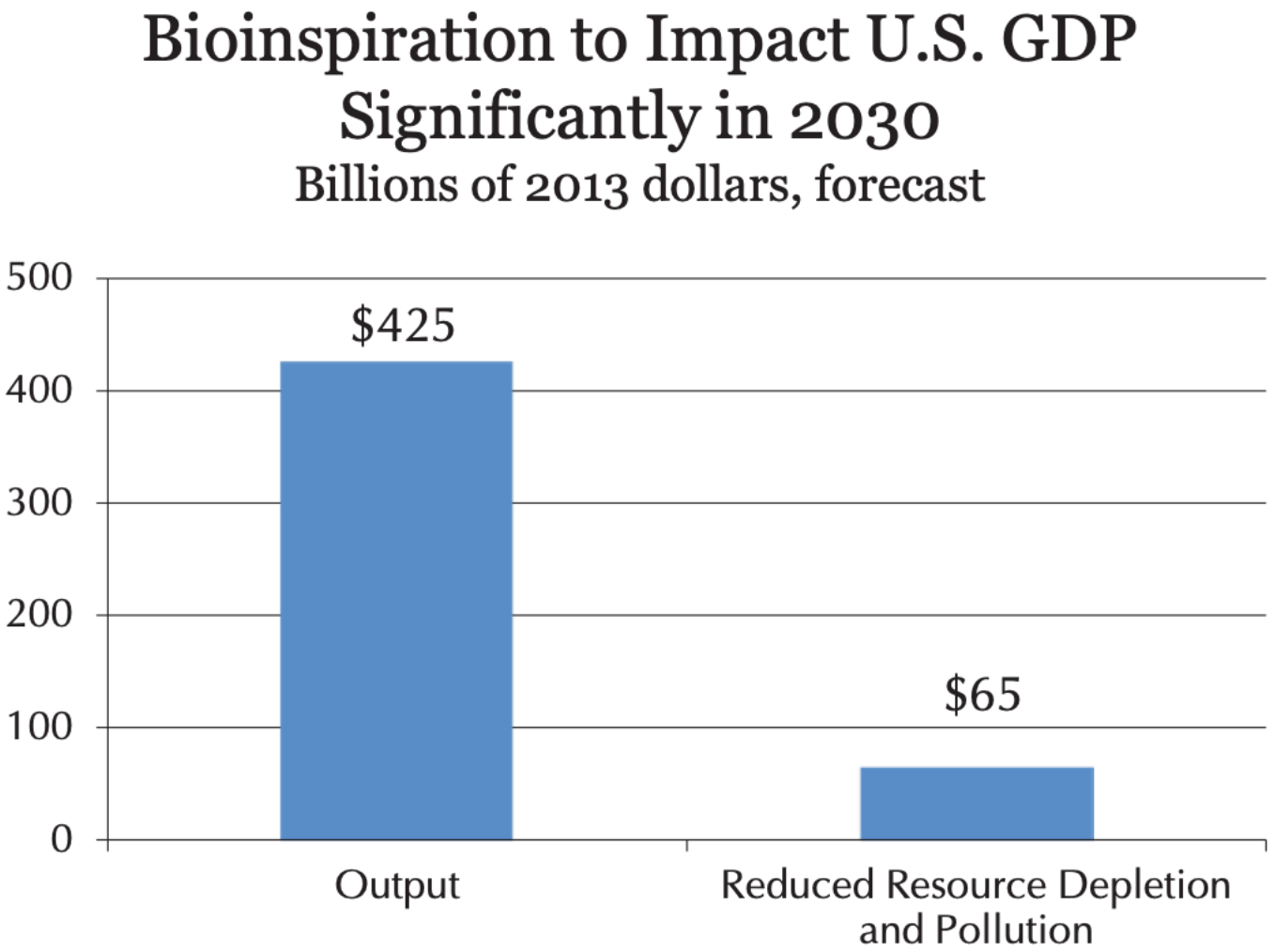




400年后奥托-滑翔机

达·芬奇绘制的飞行器雏形
（一生的飞行梦想）

Why 仿生研究?

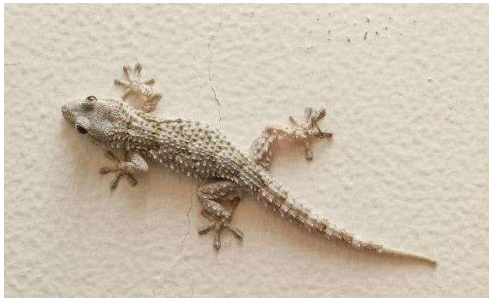


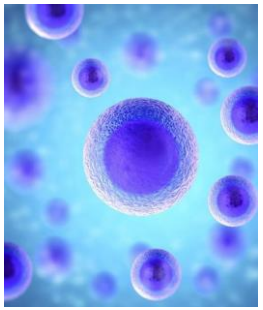
全球贡献1.6万亿美元

仿生界面材料

仿生粘附

Bioinspired adhesion





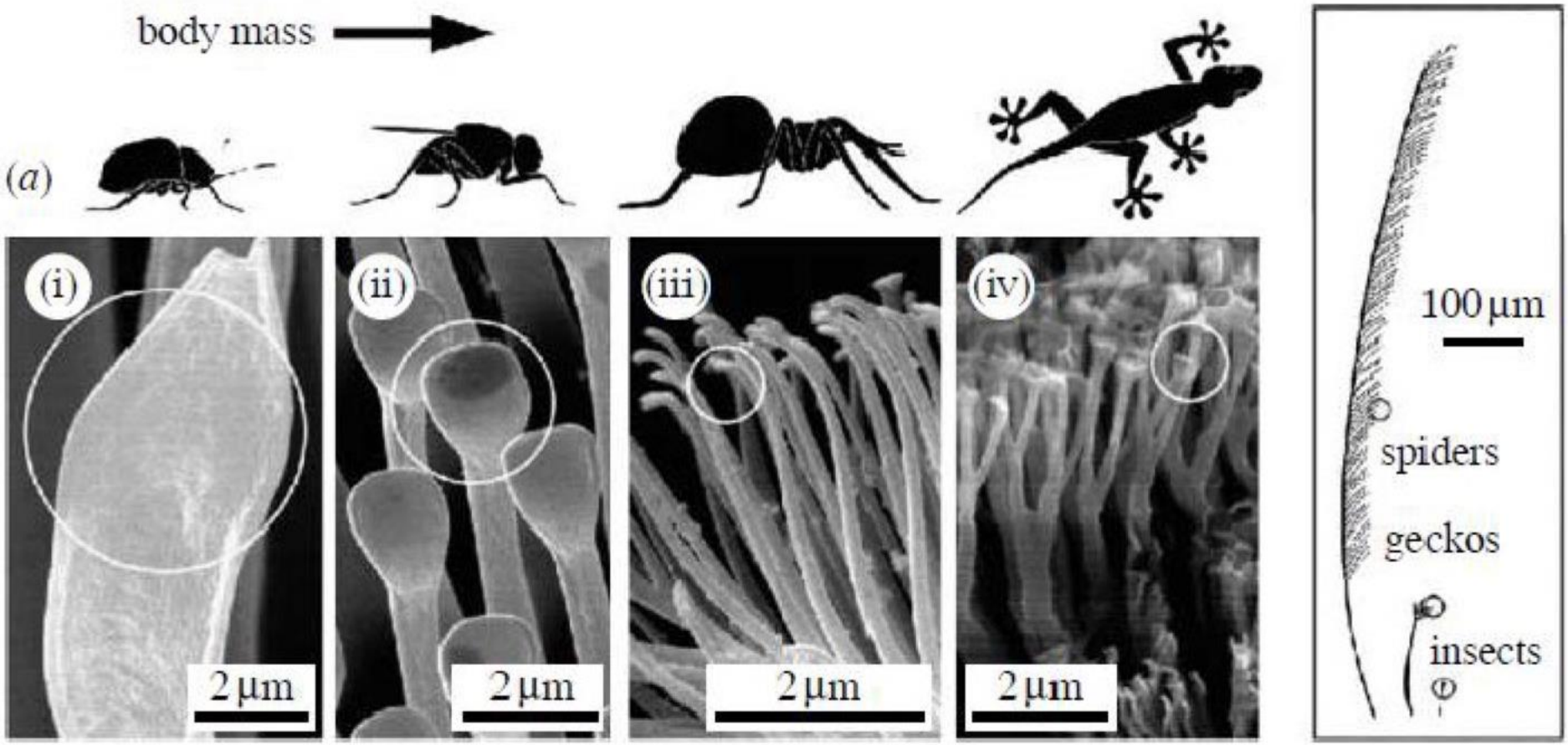
仿生抗粘附

Bioinspired anti-adhesion

仿生粘附大师

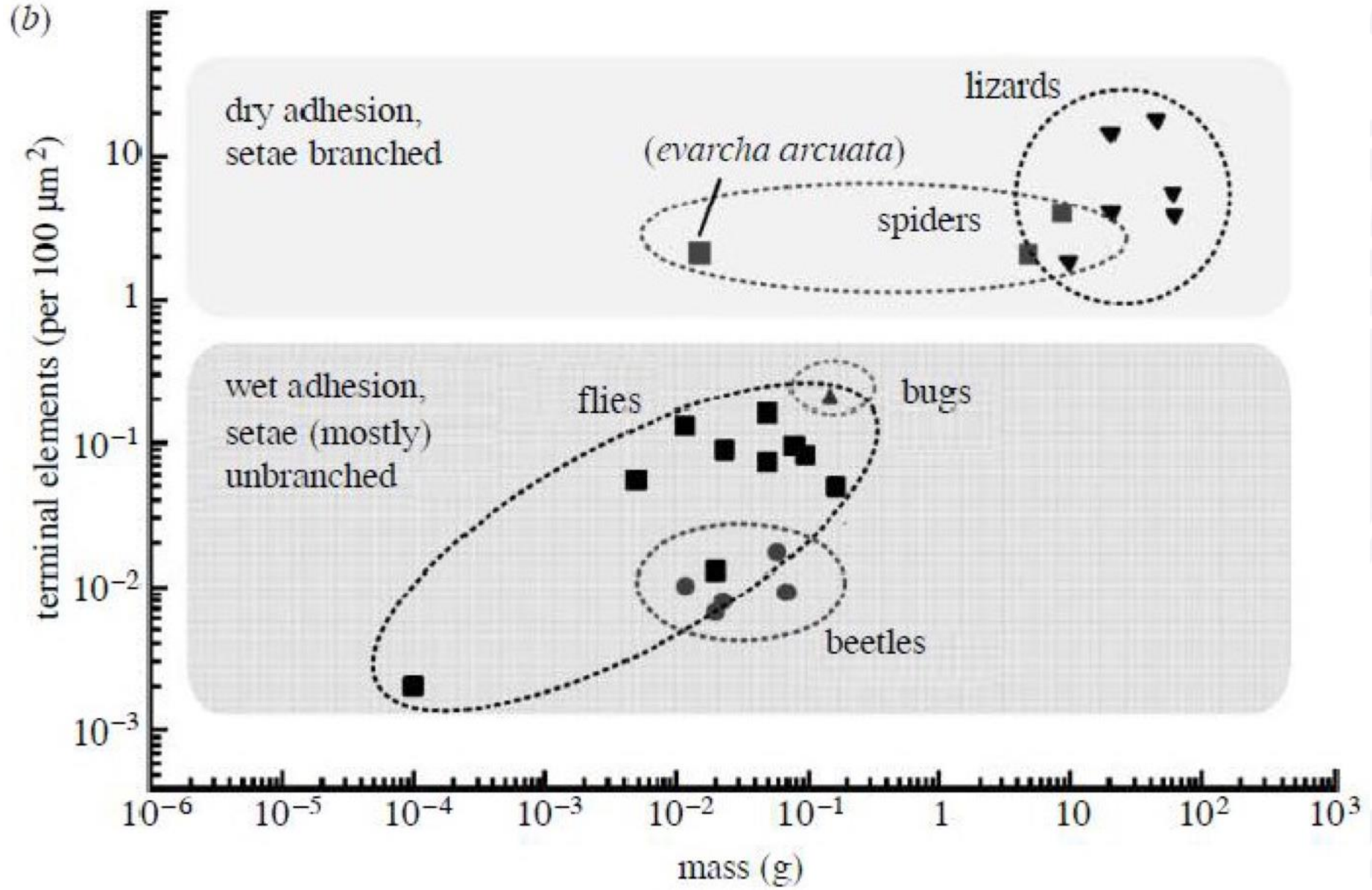
干法粘附
湿法粘附

1：干法粘附：自然大师



甲虫、苍蝇（湿粘附）、蜘蛛、壁虎（干粘附）
随着生物尺寸增加，终端吸附单元的尺寸减小

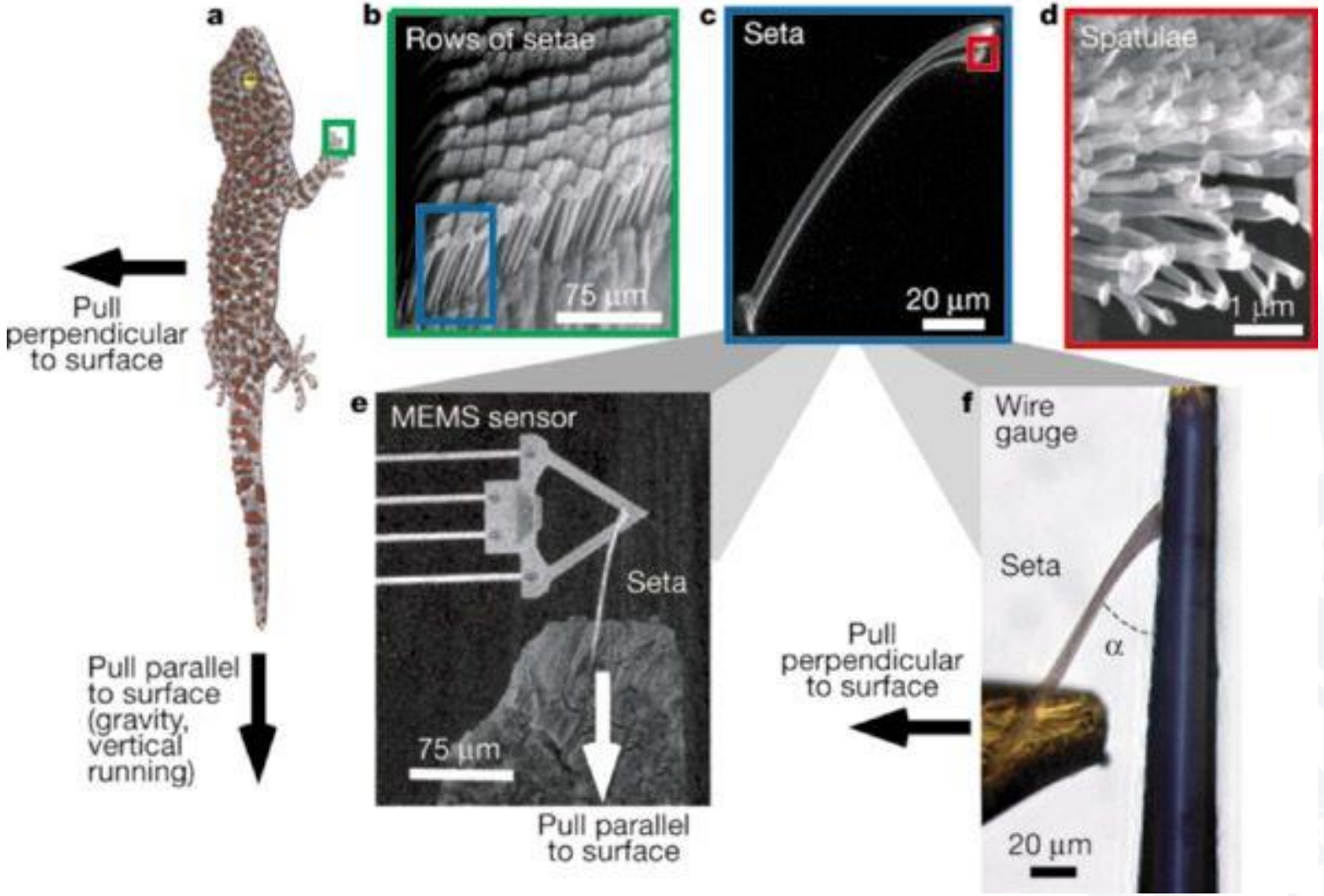
1：干法粘附：自然大师


(b)
dry adhesion,
setae branched
lizards
(evarcha arcuata)
spiders
wet adhesion,
setae (mostly)
unbranched
flies
bugs
beetles
terminal elements (per 100 μm²)
10
1
10⁻¹
10⁻²
10⁻³
10⁻⁶
10⁻⁵
10⁻⁴
10⁻³
10⁻²
10⁻¹
1
10
10²
10³
mass (g)

1：干法粘附：自然大师

飞檐走壁的壁虎（神奇的壁虎）

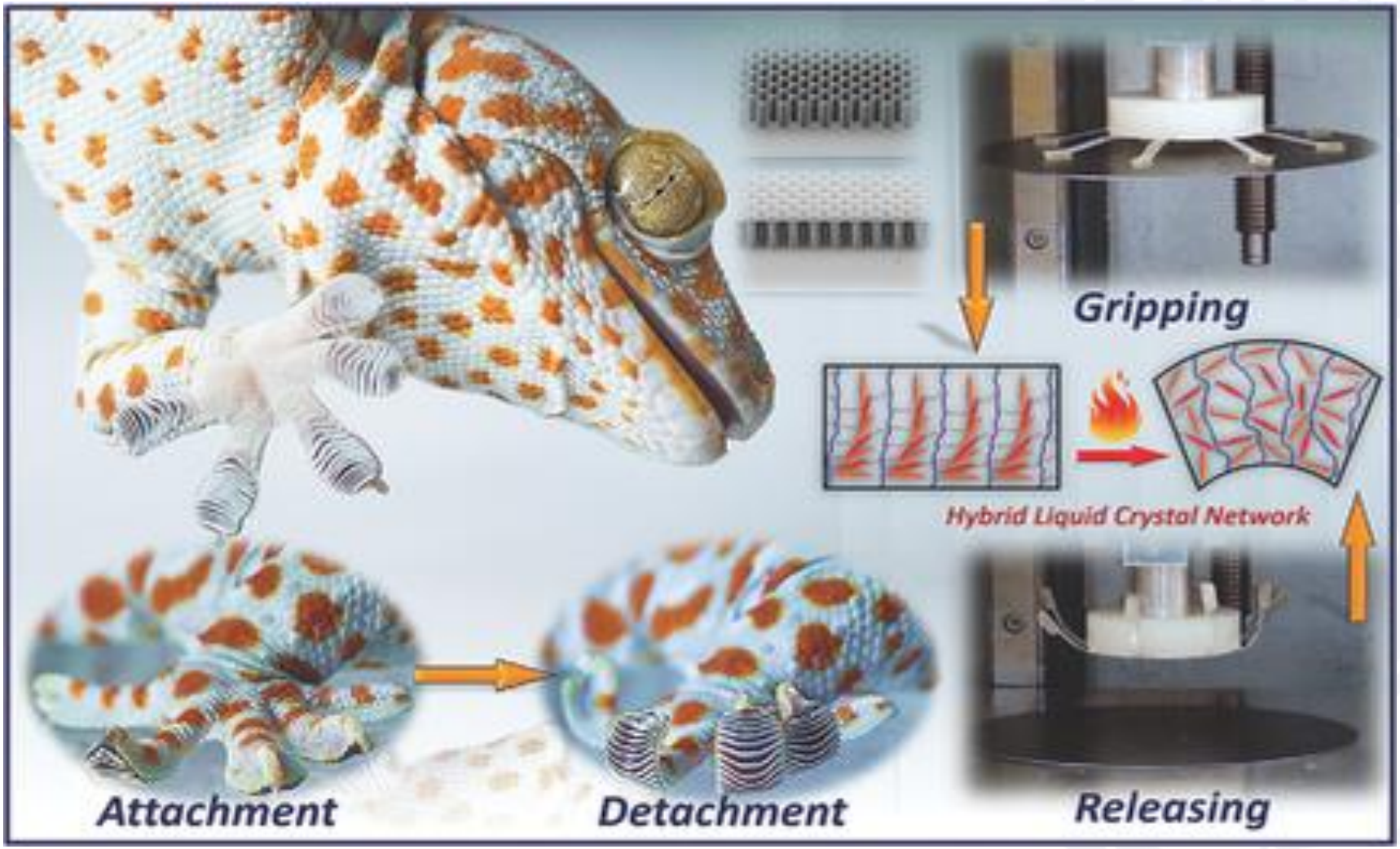
Adhesive force of a single gecko foot-hair



刚毛末端绒毛与壁面间的分子间力
超可控；无限重复；适应面广；节能

Nature 2000 **405:** 681–685 (UCB)

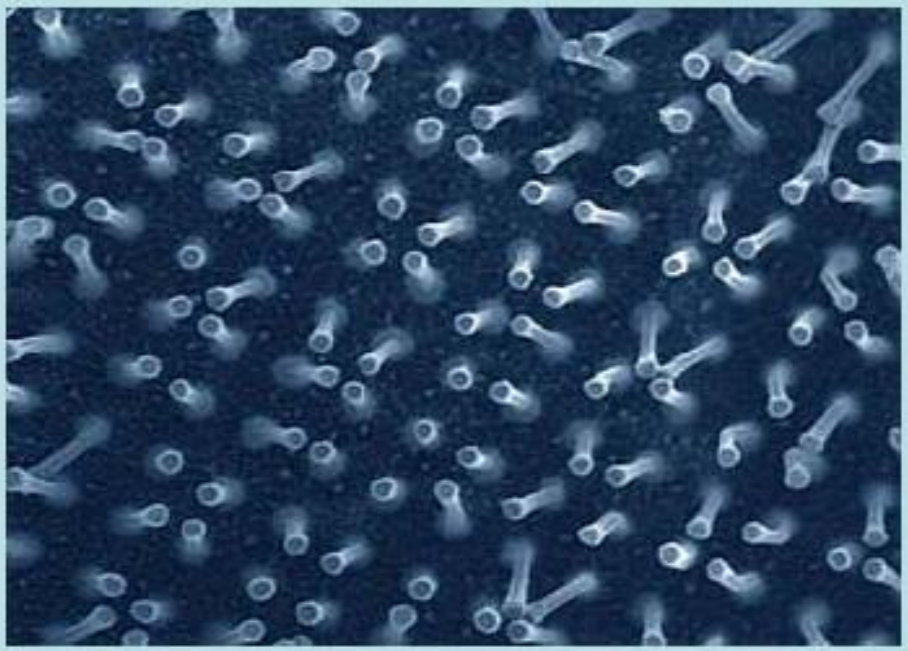
干法仿生粘附

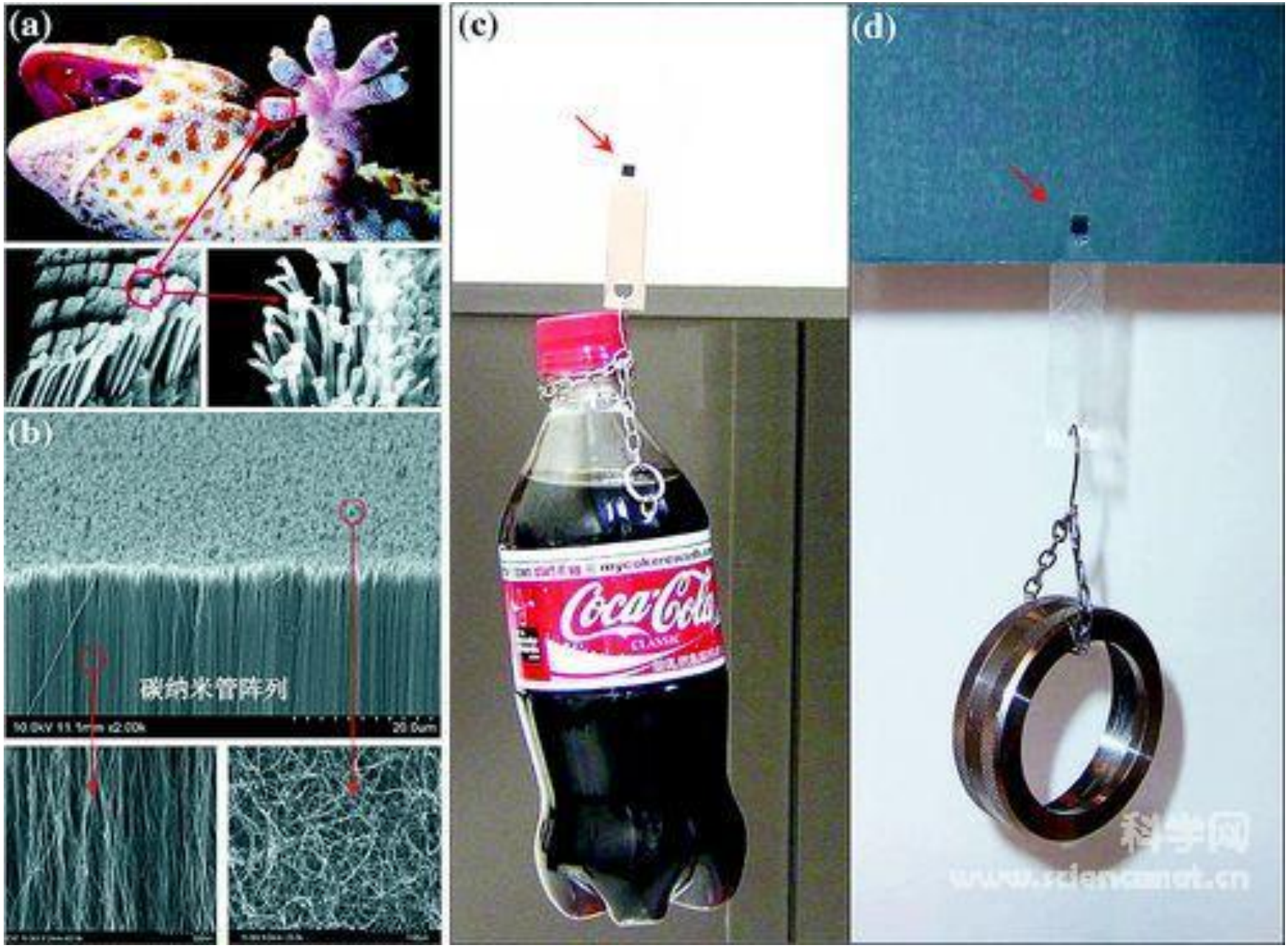


模仿壁虎脚趾垫自剥的热活性液晶网络夹持器

Zhao BX, Adv Mater 2017, 29: 1604021*

Gecko-Tape

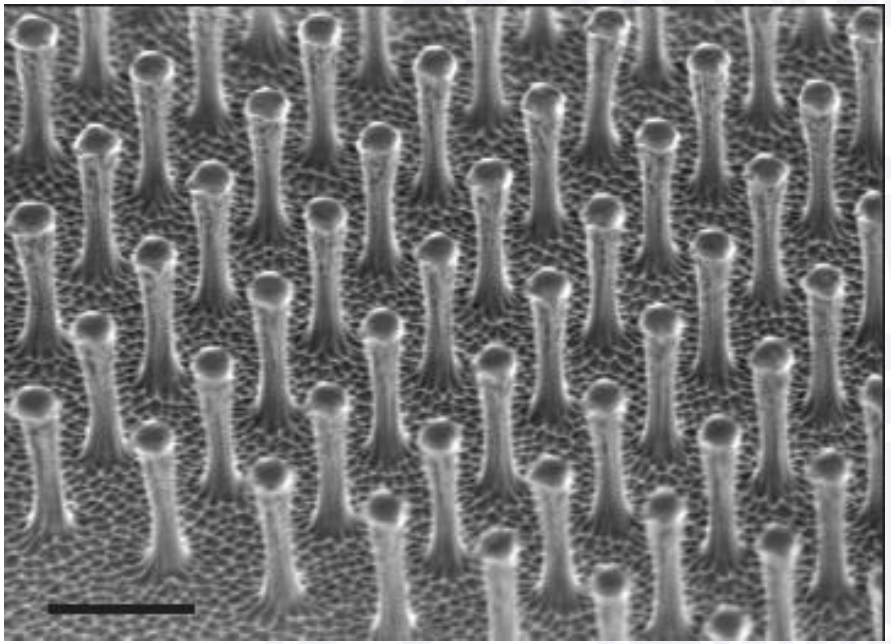




神奇粘钩

王中林院士

Microfabricated adhesive mimicking gecko foot-hair



蜘蛛侠玩偶的右手掌心处是他们模仿蜥蜴掌纹开发出的的新干燥粘性材料，蜘蛛侠通过这层材料被吸附在玻璃板上。

Geim AK, Nat Mater 2013, **2**: 461–463

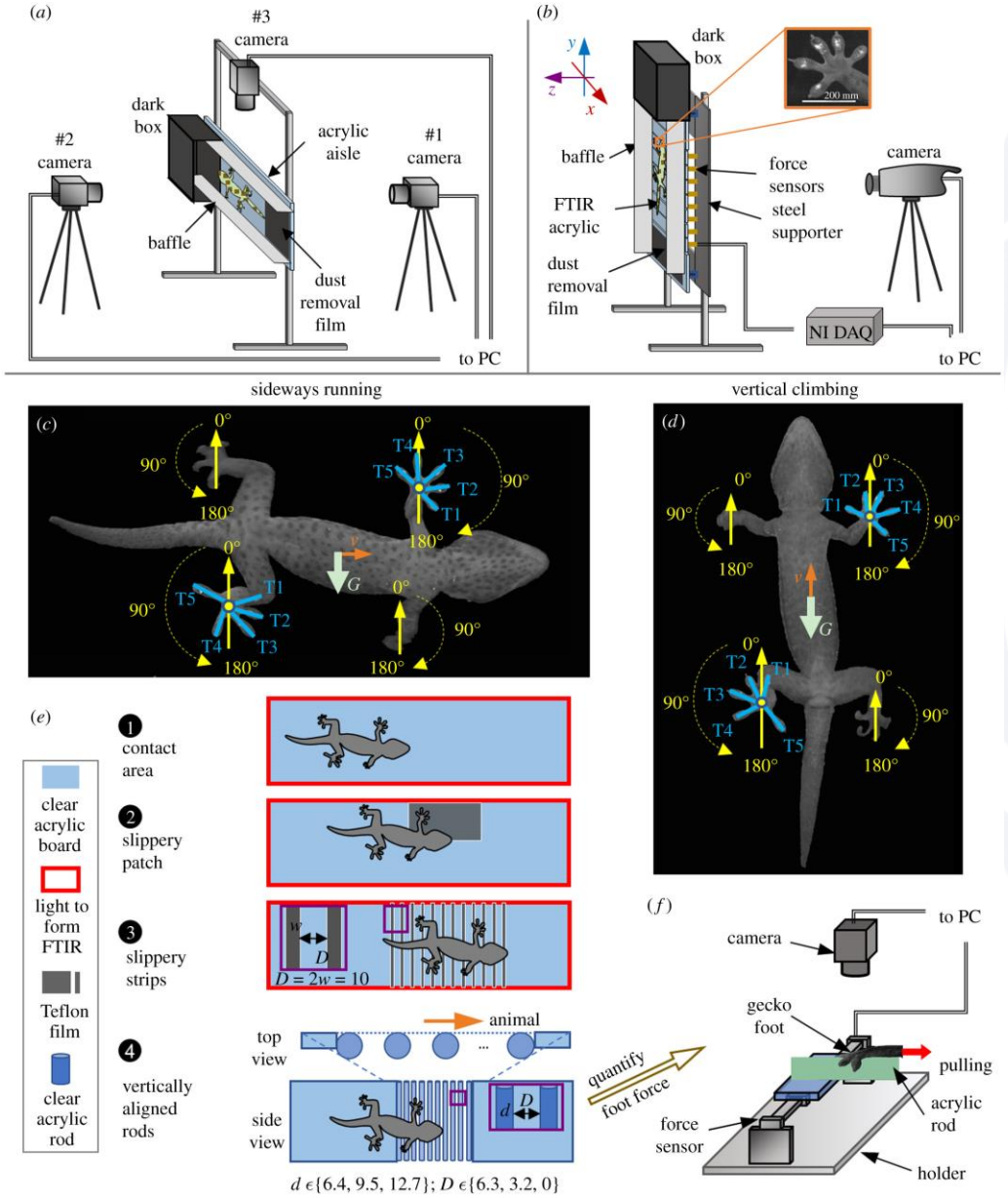
壁虎手套: 一秒变身壁虎侠

目前还只能向上爬

Z-Man研发的壁虎手套

戴振东 教授

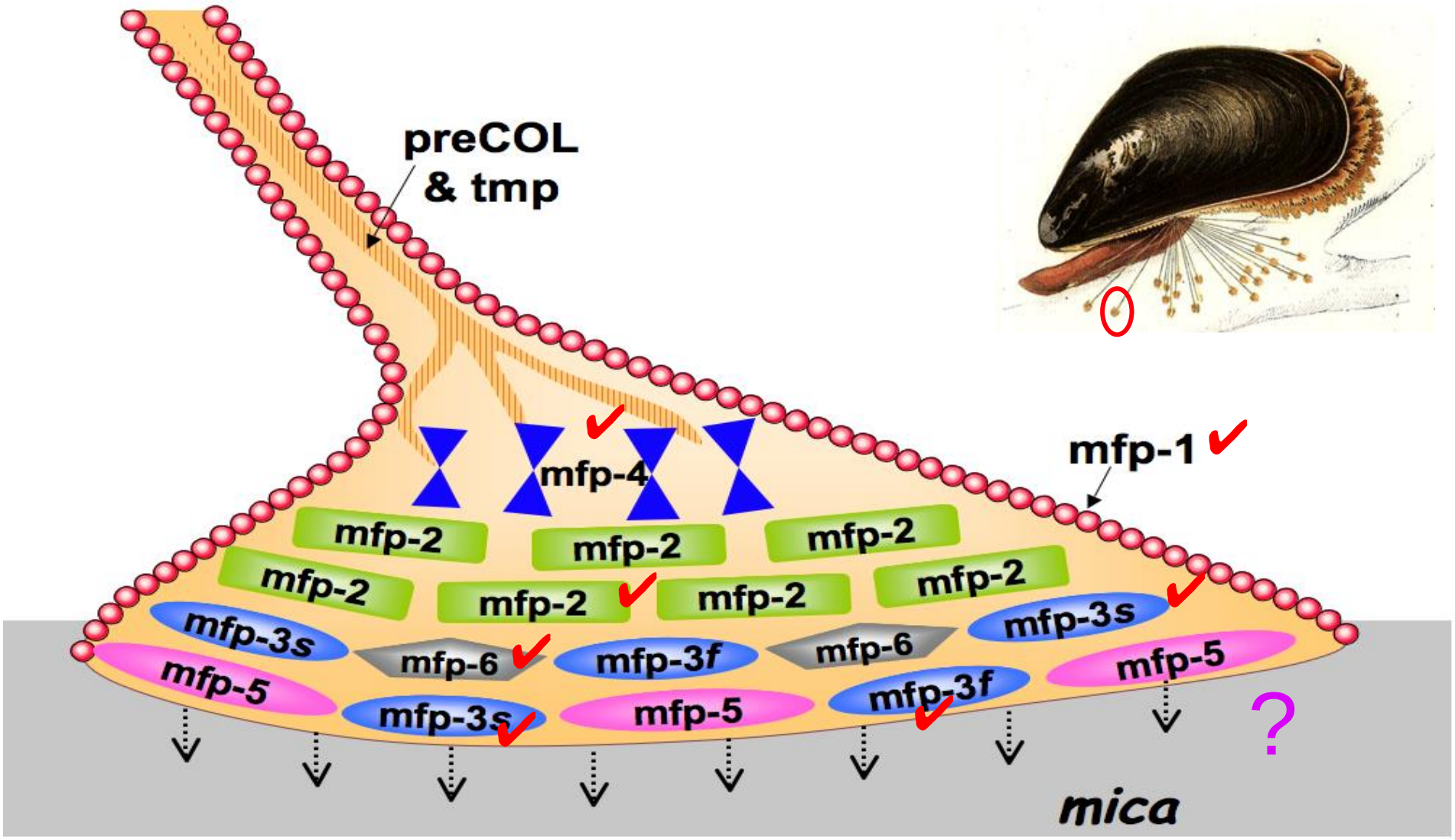
Robert J. Full



2：湿法粘附：自然大师

贻贝为什么这么“粘人”？

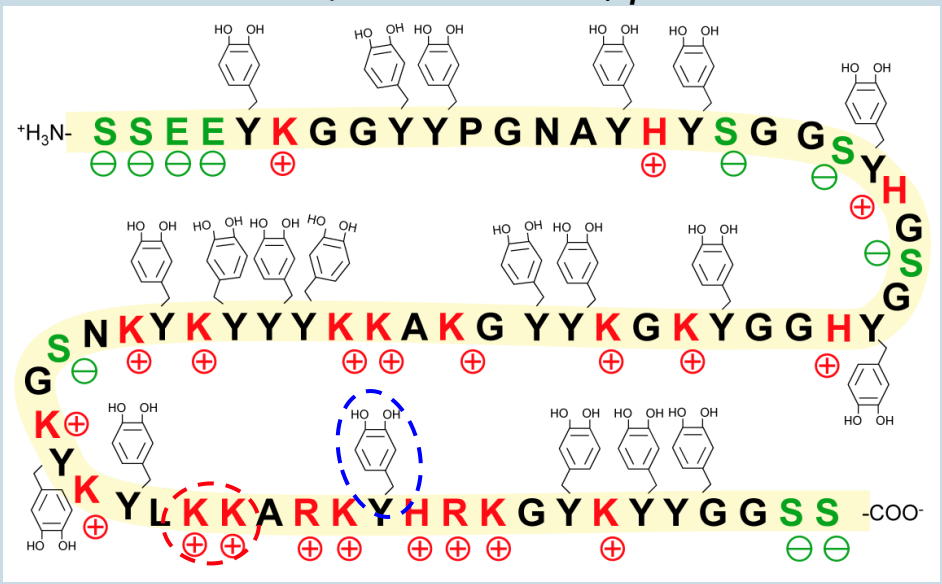
贻贝足丝蛋白


preCOL
& tmp
mfp-4
mfp-1
mfp-2
mfp-2
mfp-2
mfp-2
mfp-2
mfp-2
mfp-2
mfp-3s
mfp-3s
mfp-6
mfp-3f
mfp-6
mfp-5
mfp-5
mfp-3s
mfp-5
mfp-3f
?
mica

Adhesion: Catechols – mfp-5

Mfp-5 primary sequence

9 kDa, random coil, pI 8.5

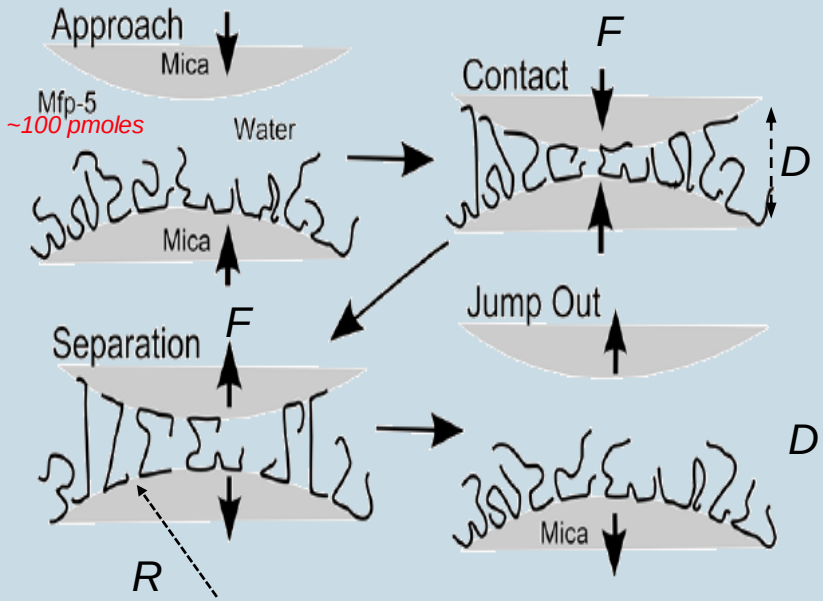


30 mol% DOPA

3, 4-dihydroxyphenylalanine

Surface Forces Apparatus

nNewton and Ångström resolution

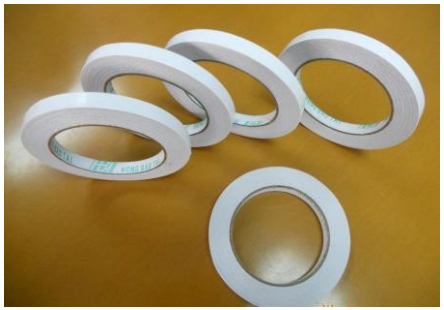


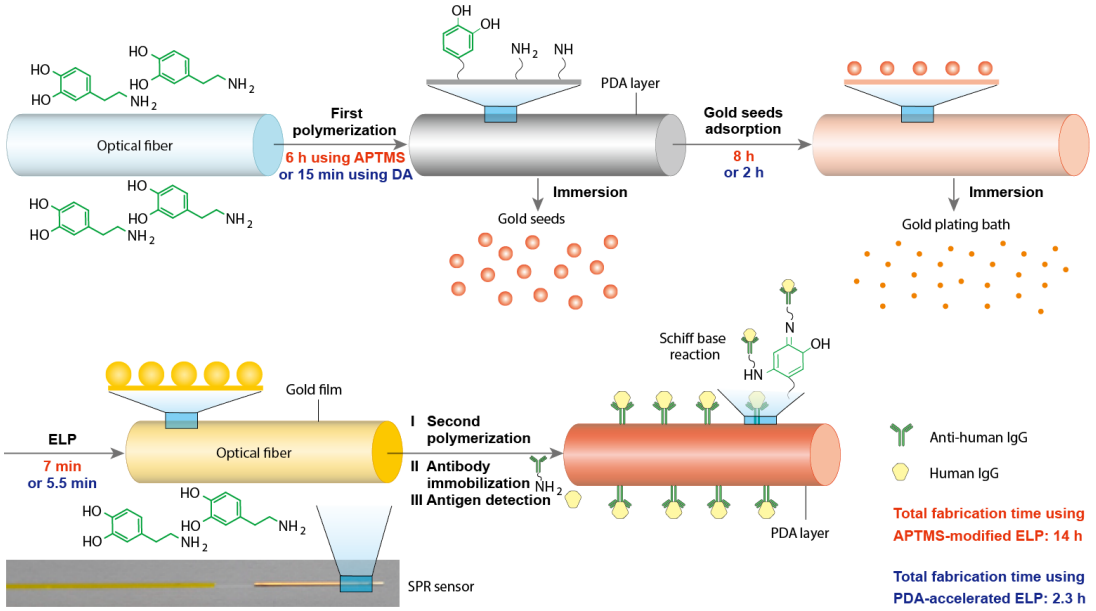
asymmetric configuration
w/ bridging adhesion

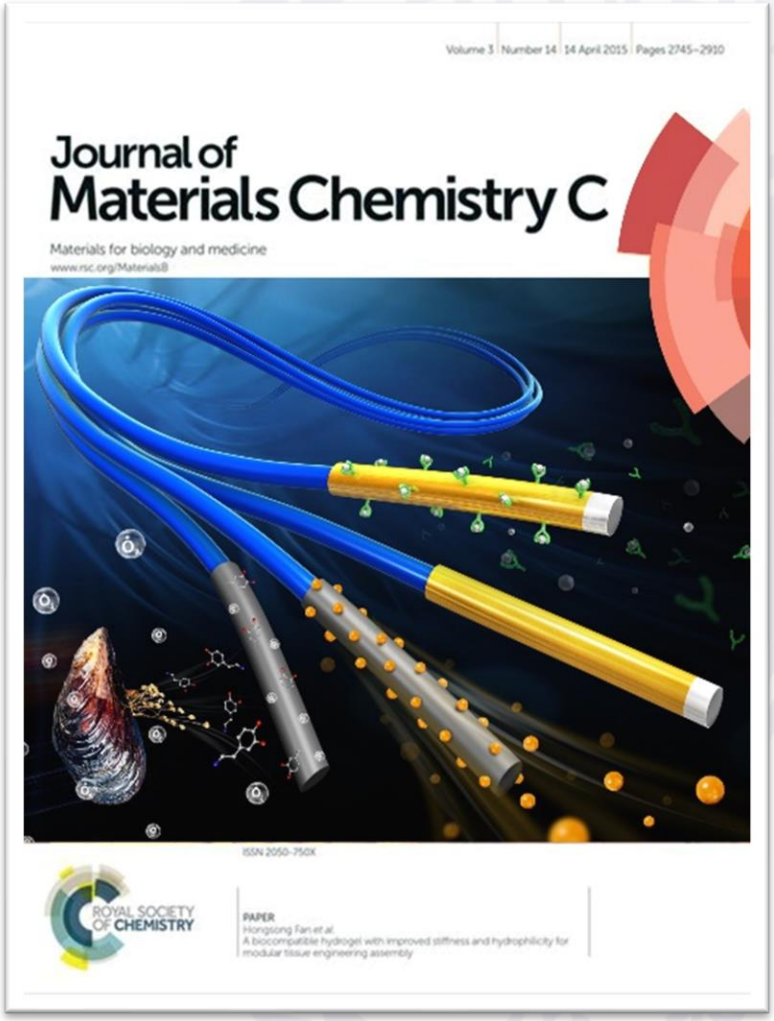
Biochemistry **2012**, *51*, 6511−6518

Danner, Kan, Waite and Israelachvili
students, post-docs, faculty

仿生粘附在生物传感器中的应用



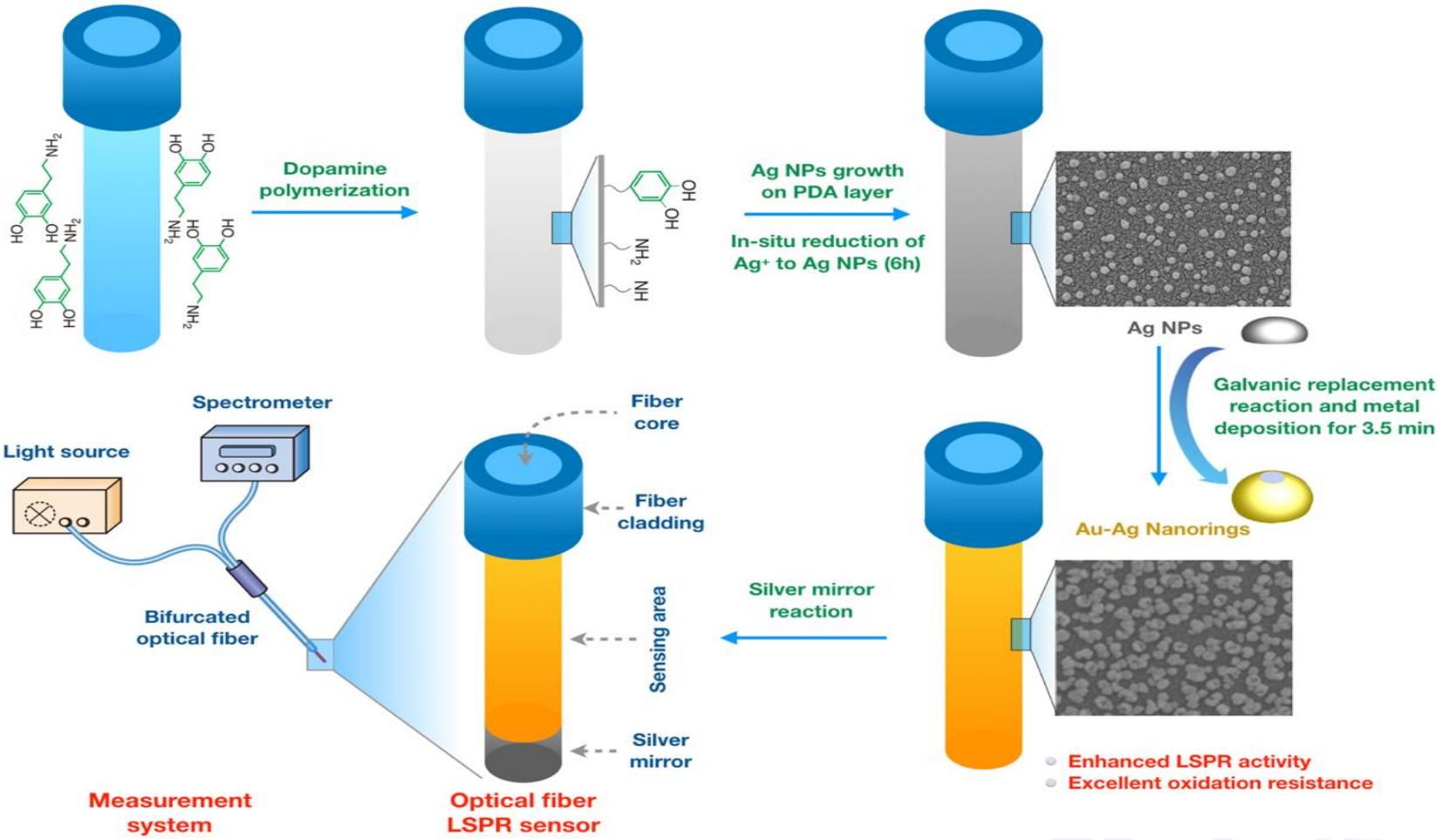




多巴胺加速湿化学法构建金膜光纤SPR传感器

Su RX, et al.* ***J Mater Chem C*** 2016, 4: 7554-7562

仿生粘附在生物传感器中的应用



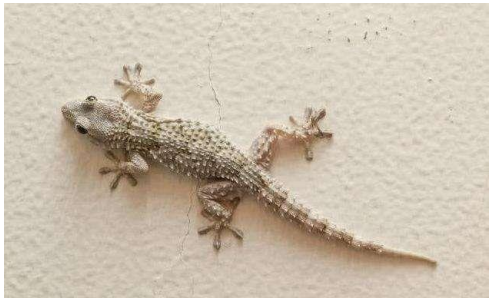
多巴胺固定还原法构建金银纳米环LSPR传感器

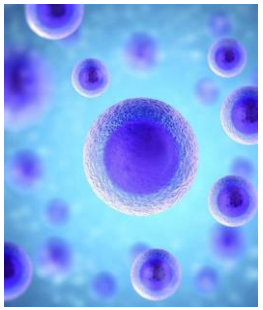
Su RX, et al.* ***J Mater Chem C*** 2020, 8: 7552-7560

仿生界面材料

仿生粘附

Bioinspired adhesion





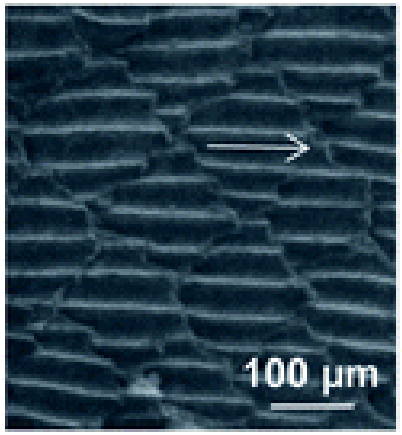
仿生抗粘附

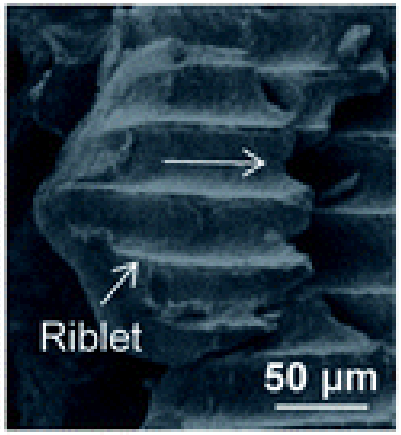
Bioinspired anti-adhesion

Bioinspired anti-adhesion

仿生界面抗粘附

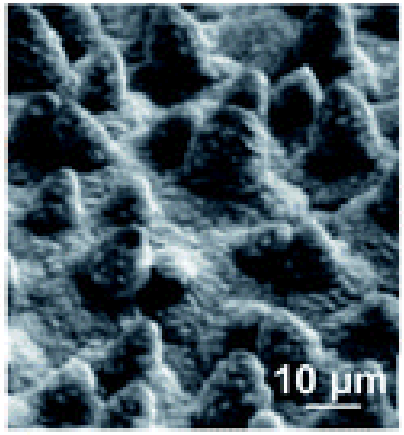
Low drag shark skin *(Mako, Isurus oxyrinchus)*

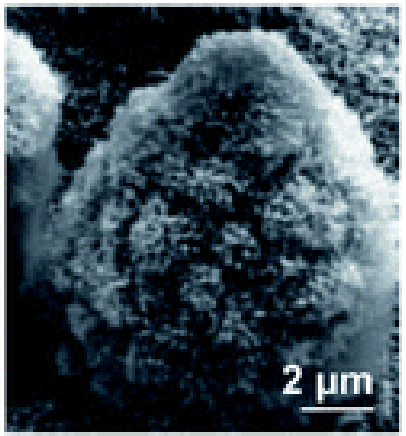




Dermal denticle

Self-cleaning Lotus leaf *(N. nucifera)*

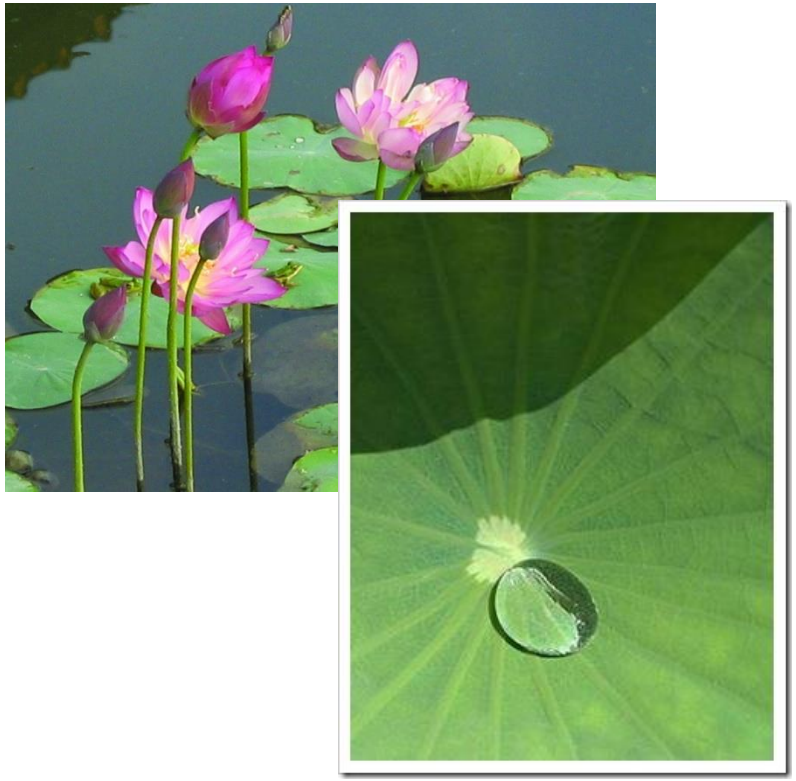




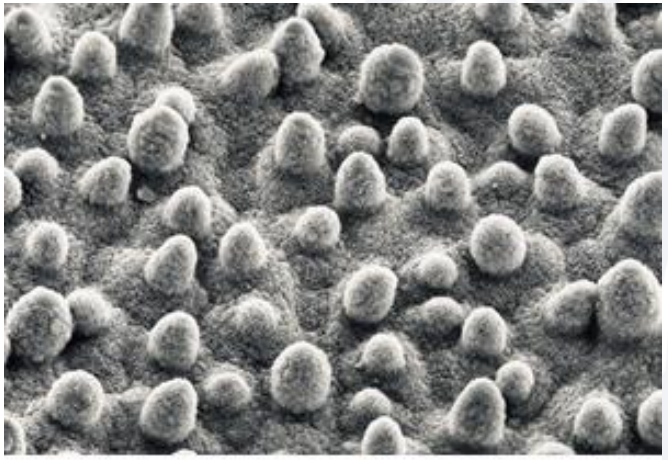
出淤泥而不染——荷叶效应

Bioinspired anti-adhesion

仿生界面抗粘附　例1 荷叶

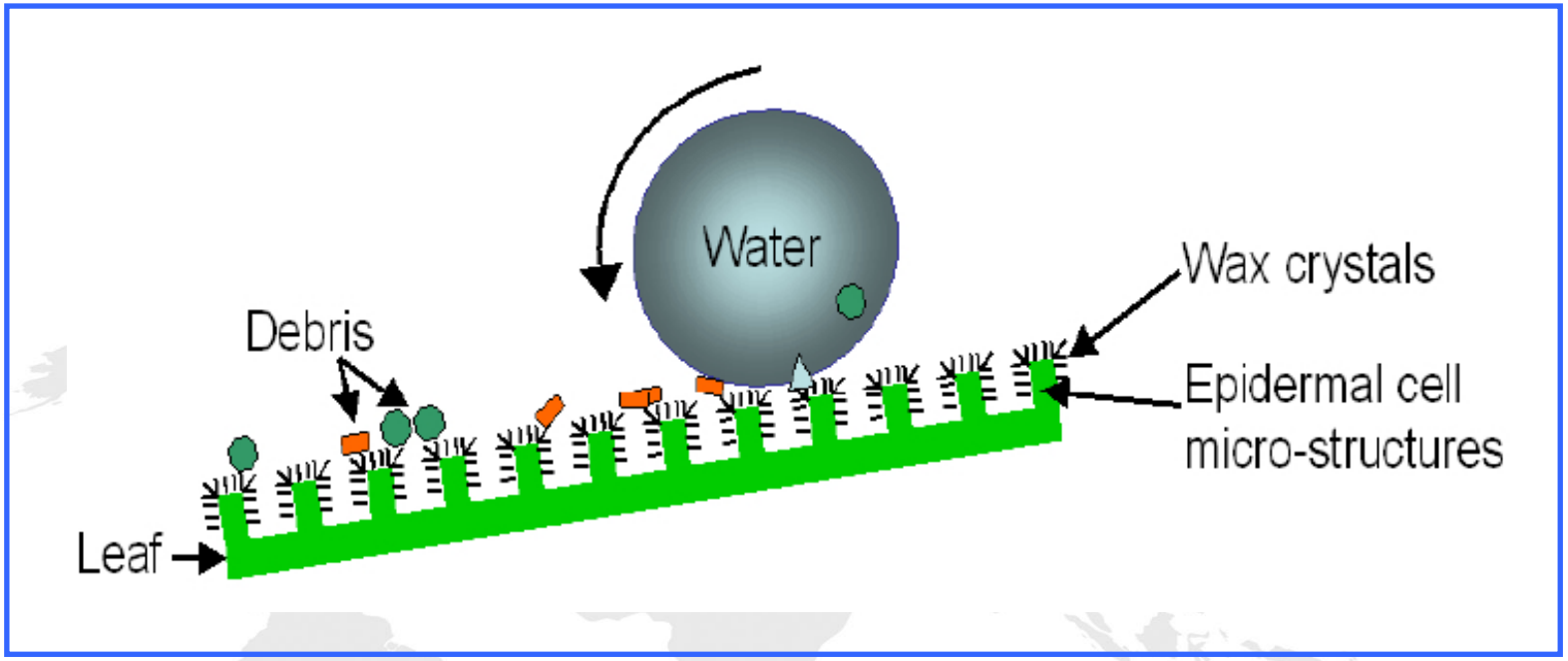


荷叶上滚动的露珠
(莲花效应)
(Lotus Effect)



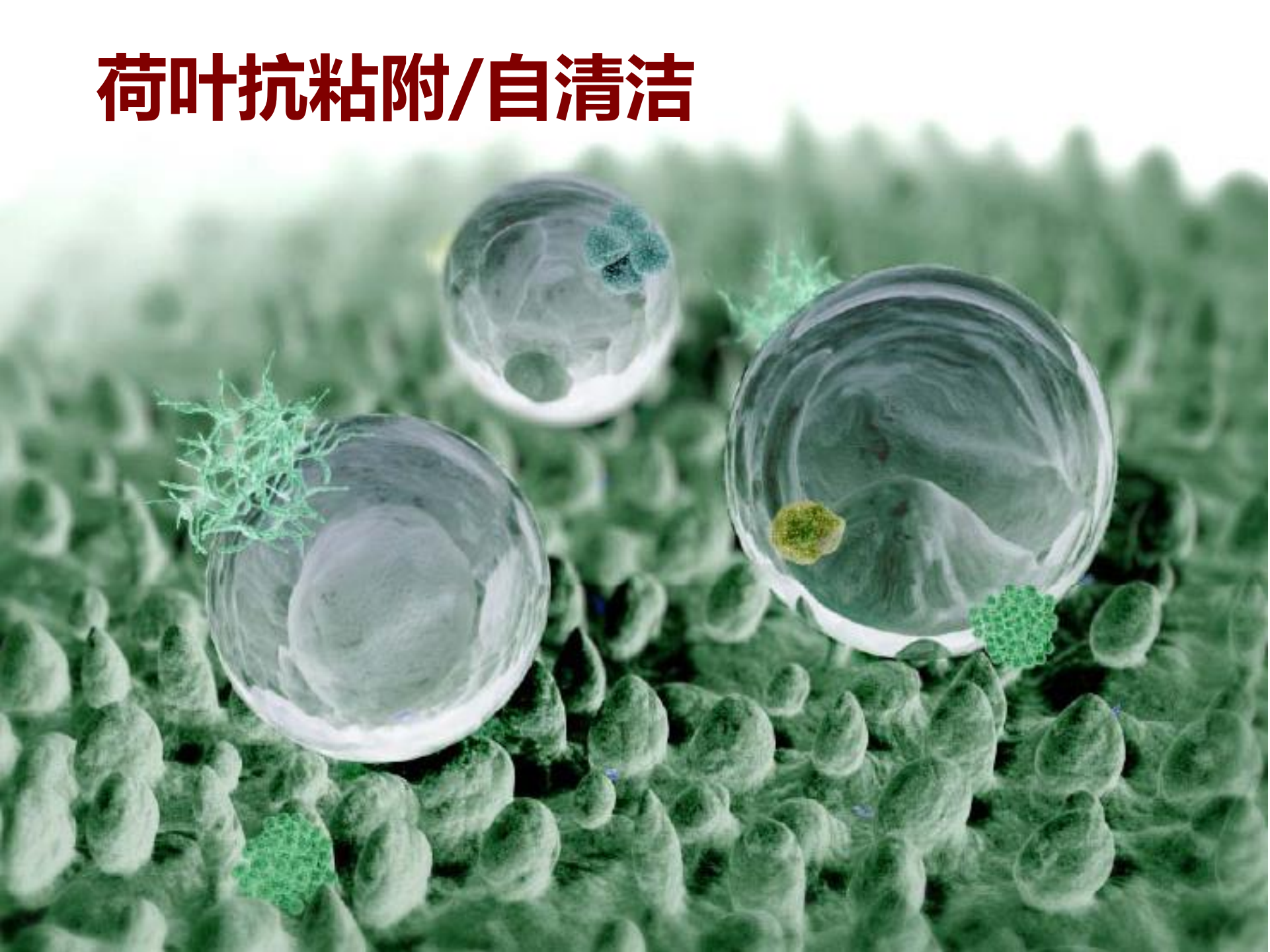
荷花的花瓣表面像毛玻璃一样毛糙，全是纳米级的“疙瘩”。这些“疙瘩”让雨水将荷叶清洗干净，从而让荷花保持最佳光合作用能力，显得精神抖擞。

荷叶抗粘附/自清洁



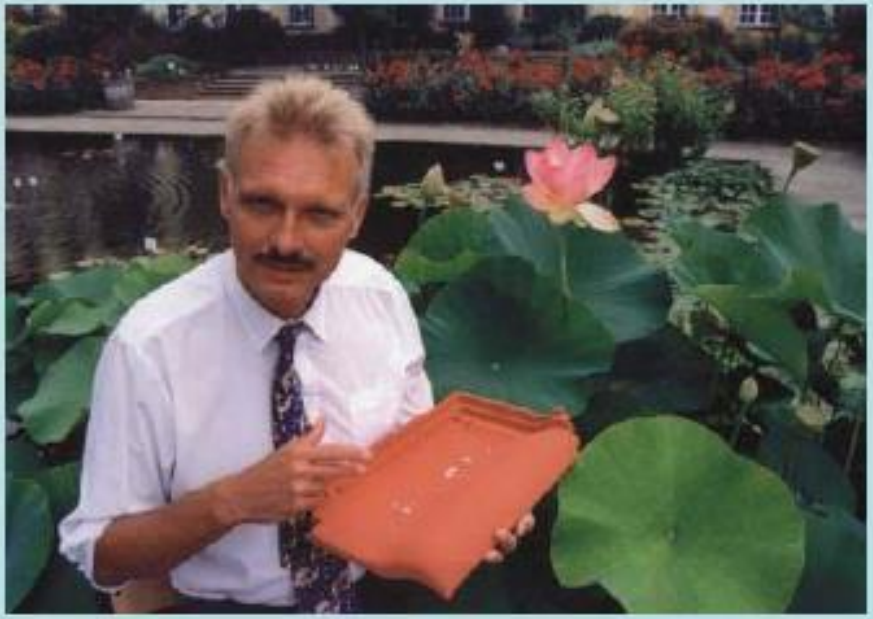
The Lotus Effect. Water forms droplets on the tips of the epidermal protrusions and collects pollutants, dirt and small insects as it rolls off the leaf.

荷叶抗粘附/自清洁



Lotus-Effect® roof tile

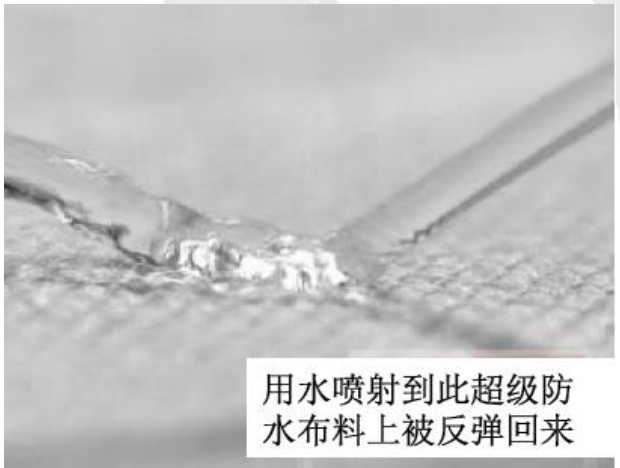
Lotus-Effect® tie



Prof. Wilhelm Barthlott

* 荷叶抗粘附/自清洁

不怕脏的仿生材料



用水喷射到此超级防水布料上被反弹回来

瑞士开发的防水布料

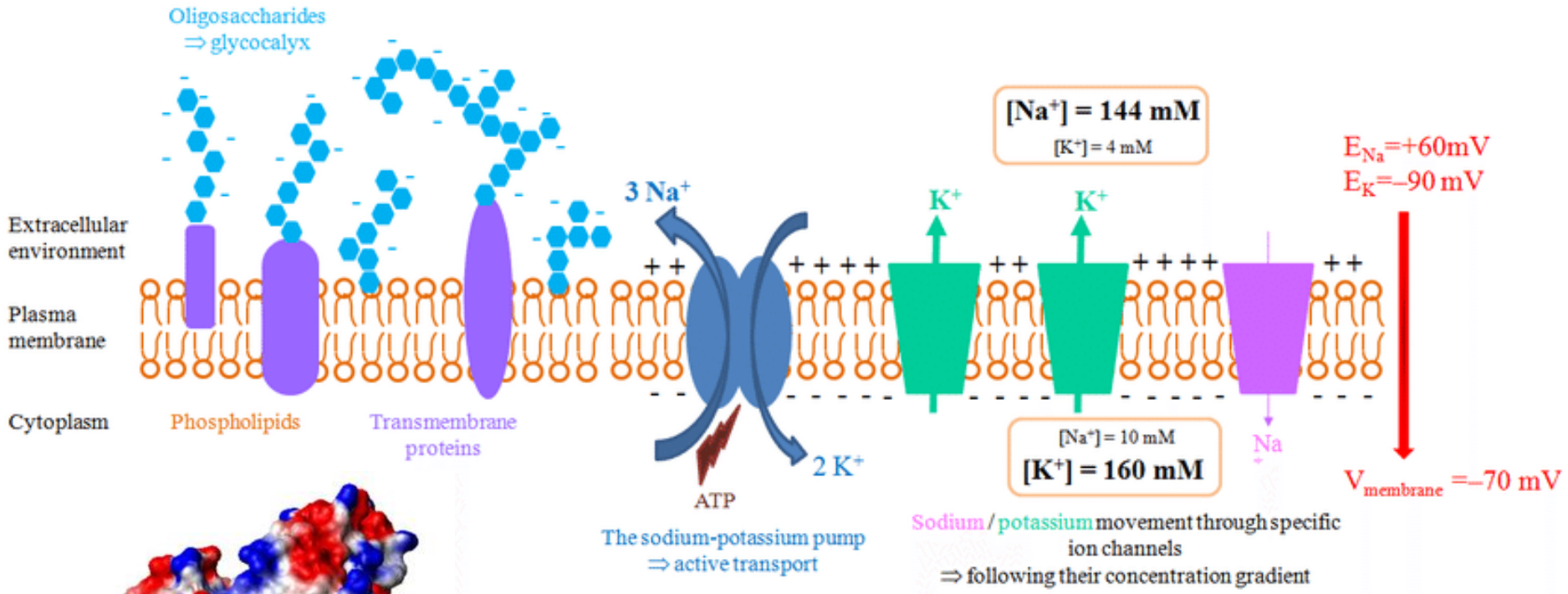
表面涂层设计

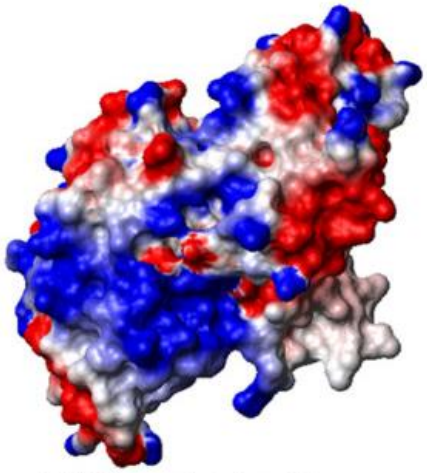
- 汽车脱下传统的外衣，换上崭新的新型外套。

由应用与汽车面漆荷叶灵感研制
的纳米材料涂层

仿生界面抗粘附

例2 细胞膜



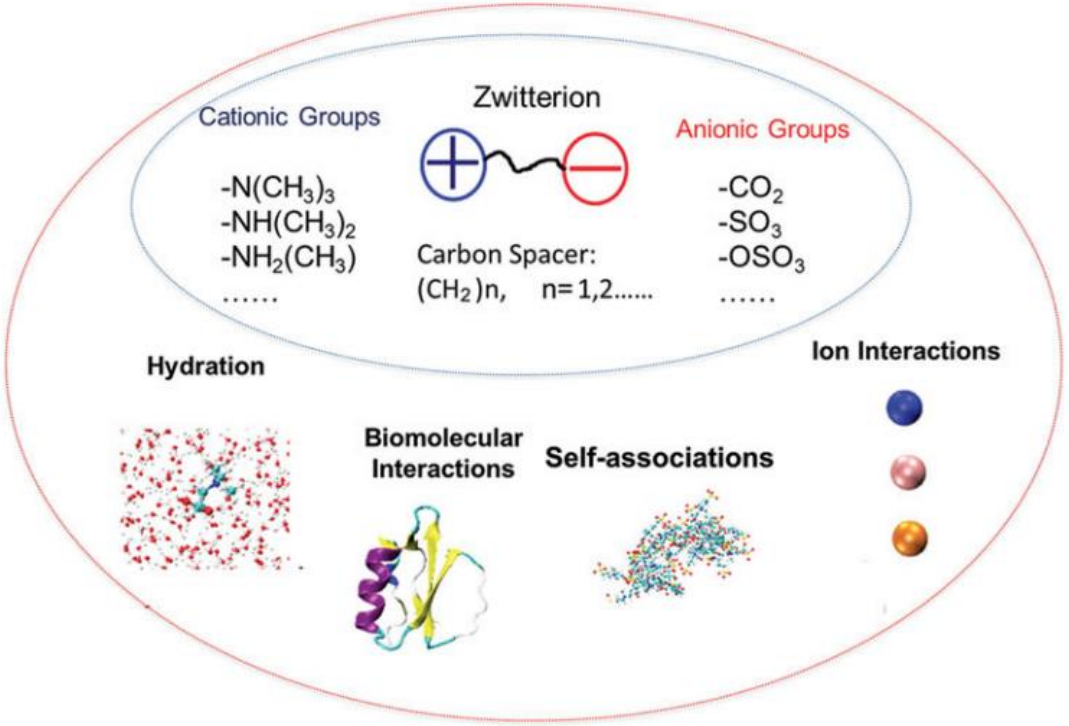


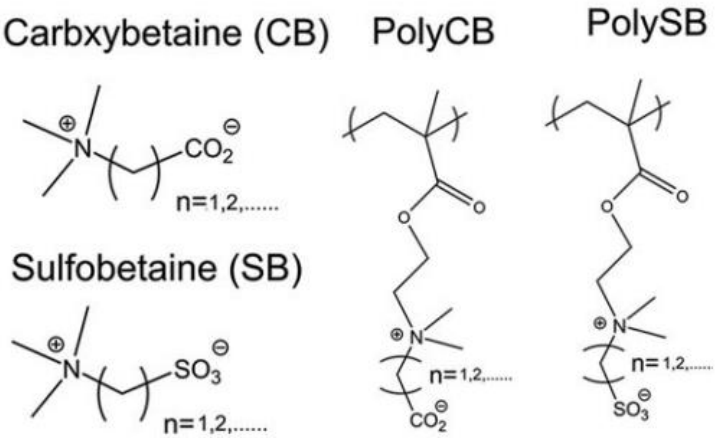
Sulfolobus solfataricus P2

两性聚合物——最强抗污染
Zwitterion polymers
仿生源头：细胞膜、蛋白质

Bioinspired anti-adhesion

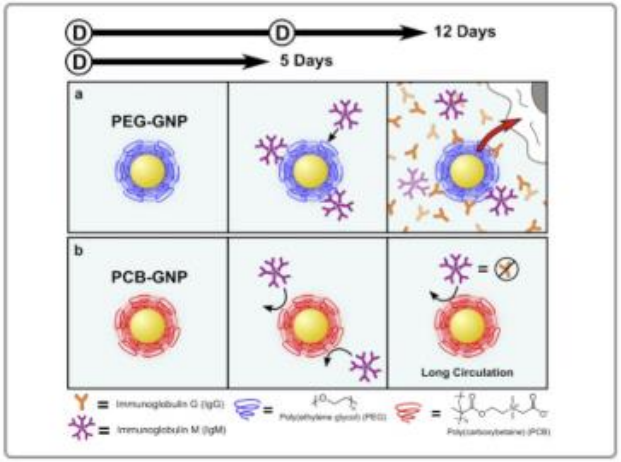
仿生界面抗粘附

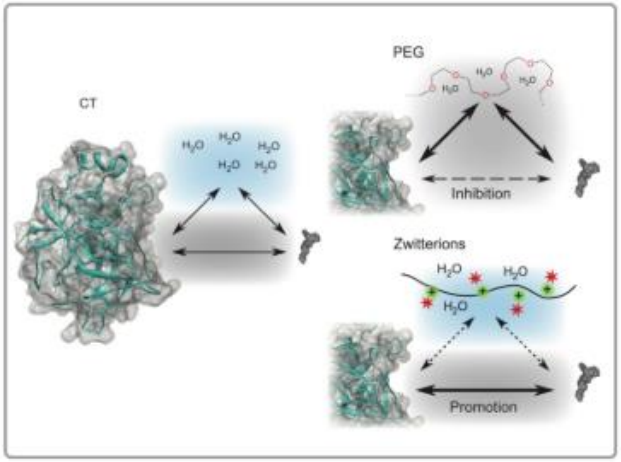


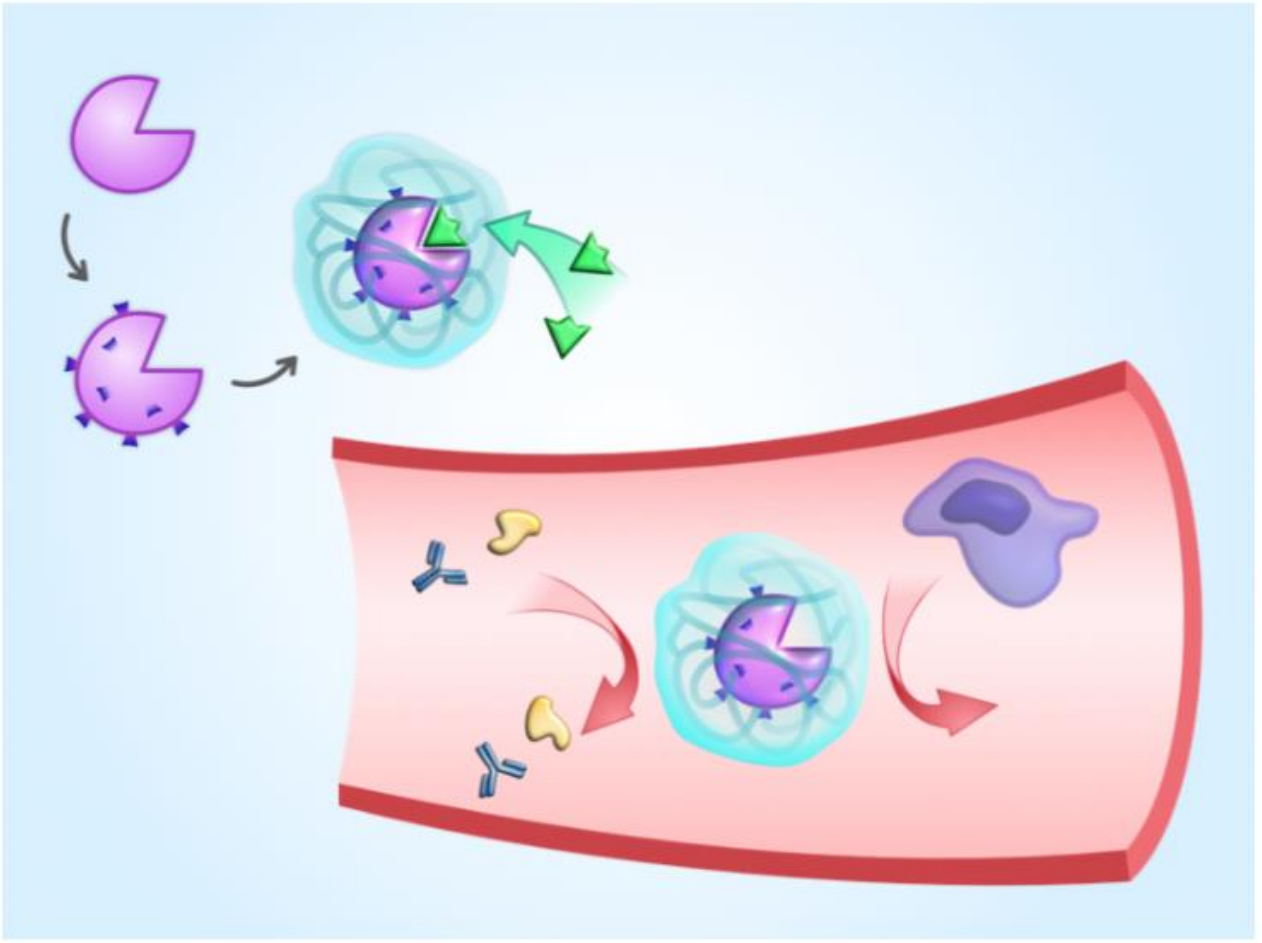


Bioinspired anti-adhesion

仿生界面抗粘附





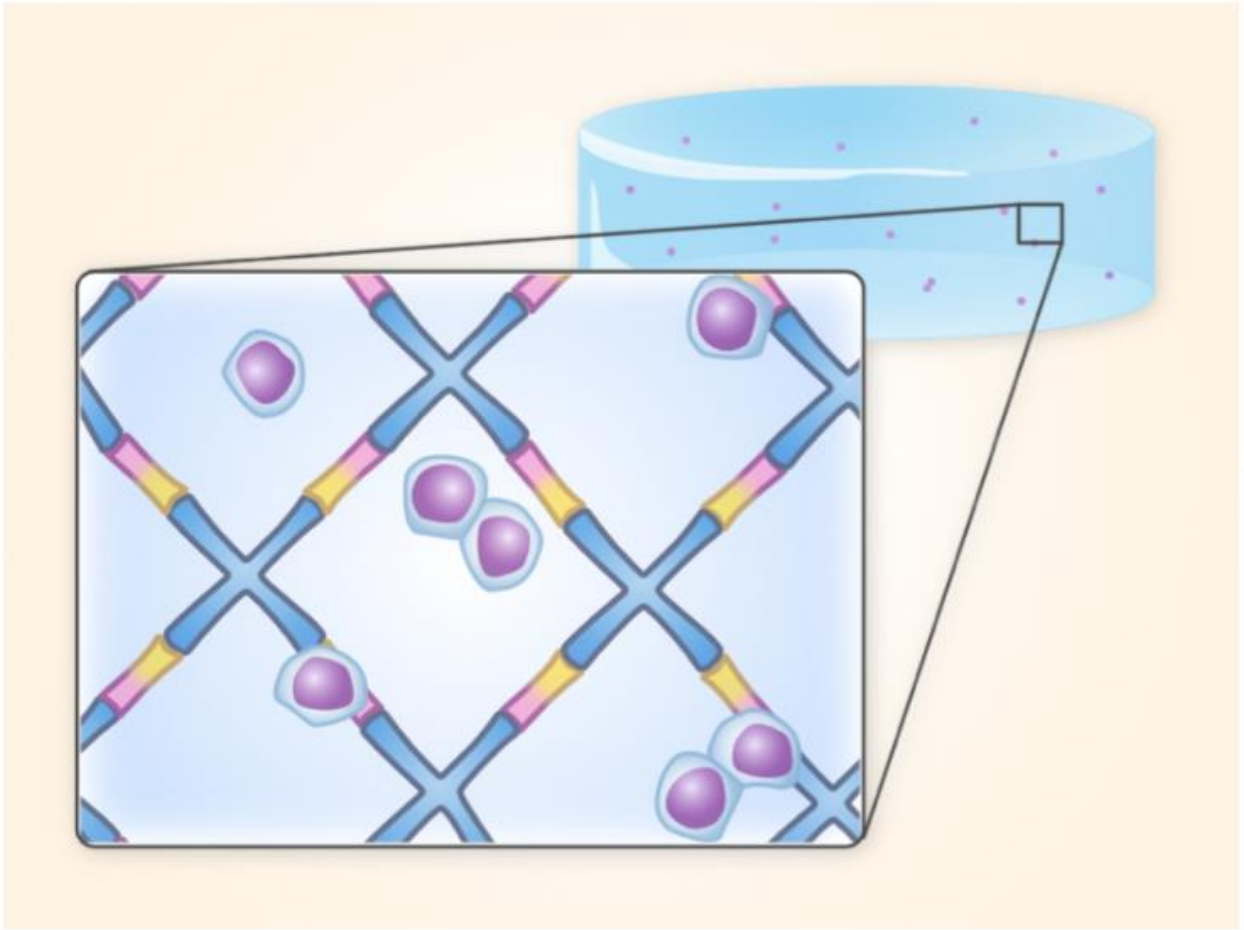


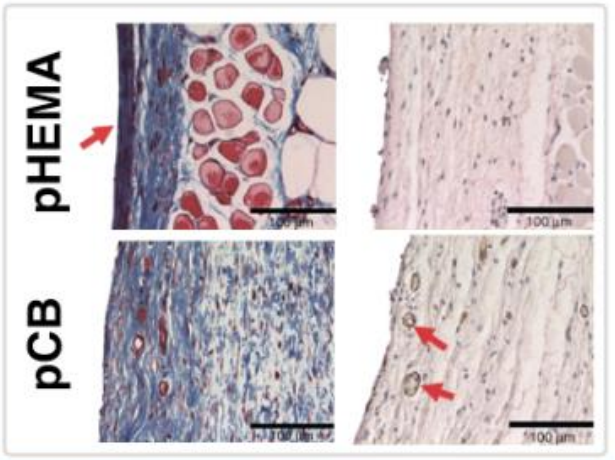
Zwitterion polymers for Nanomedicine

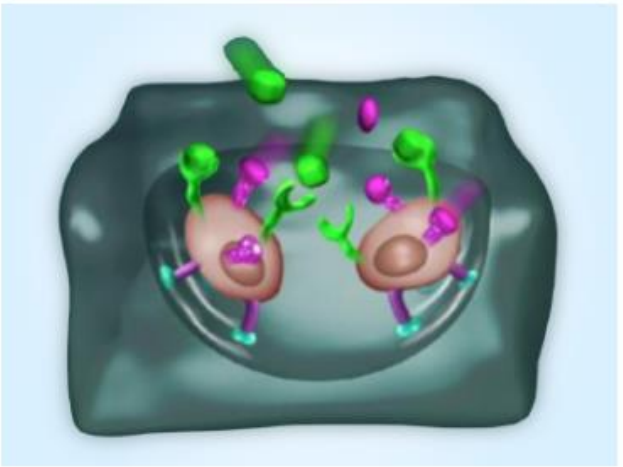
Zwitterionic gel encapsulation promotes protein stability, enhances pharmacokinetics, and reduces immunogenicity, PNAS (2015)

Bioinspired anti-adhesion

仿生界面抗粘附





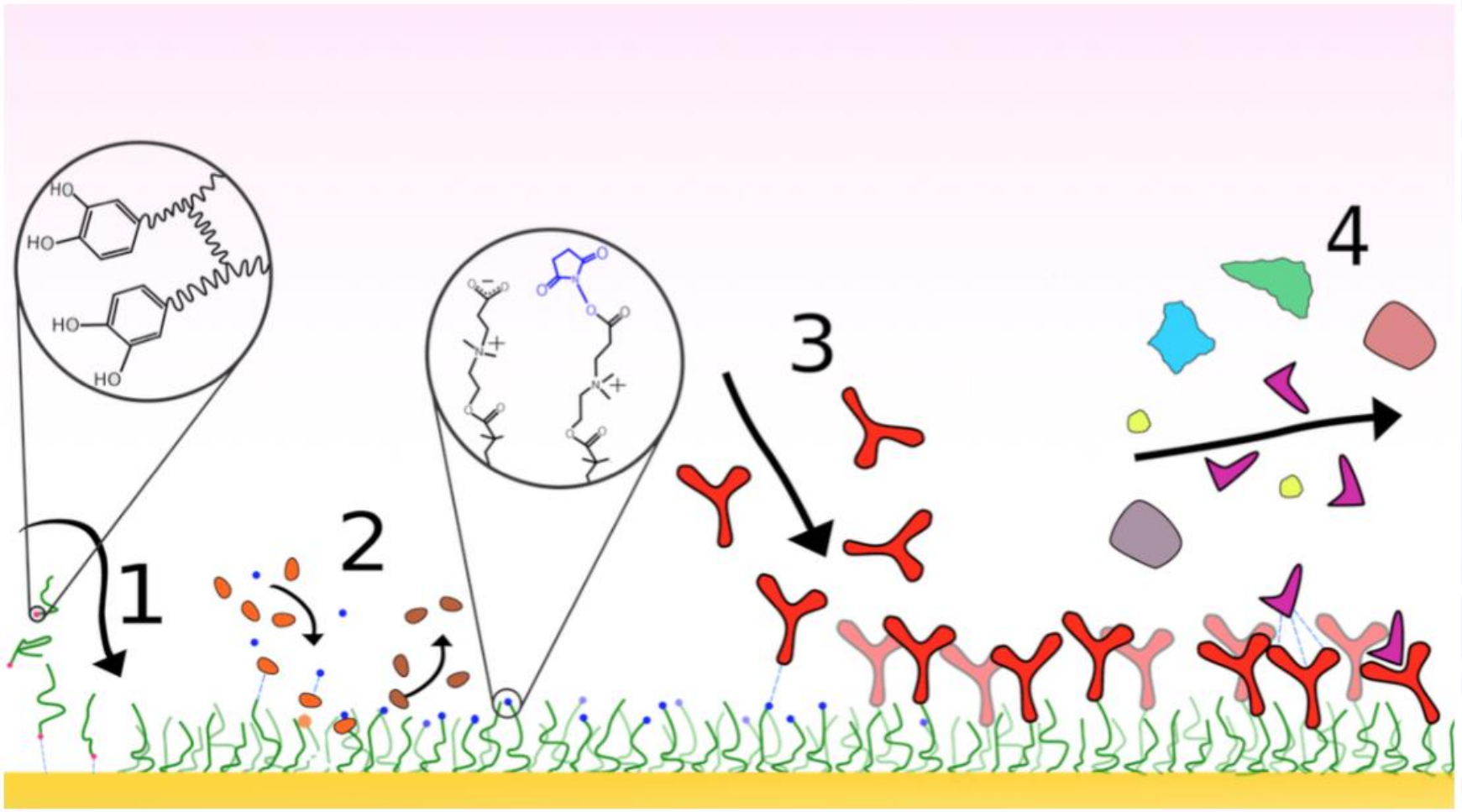


Zwitterion polymers for Hydrogels

Restraint of the Differentiation of Mesenchymal Stem Cells by a Nonfouling Zwitterionic Hydrogel, Angewandte Chemie (2014)

Bioinspired anti-adhesion

仿生界面抗粘附



Zwitterion polymers for Coatings and Diagnostics

Zwitterionic hydrogels implanted in mice resist the foreign-body reaction, Nature Biotechnology (2013)
Directly Functionalizable Surface Platform for Protein Assays in Undiluted Human Blood Plasma, Anal Chem (2013)

Bioinspired anti-adhesion

仿生界面抗粘附

Zwitterion polymers for Environmentally benign marine coatings

Bioinspired anti-adhesion

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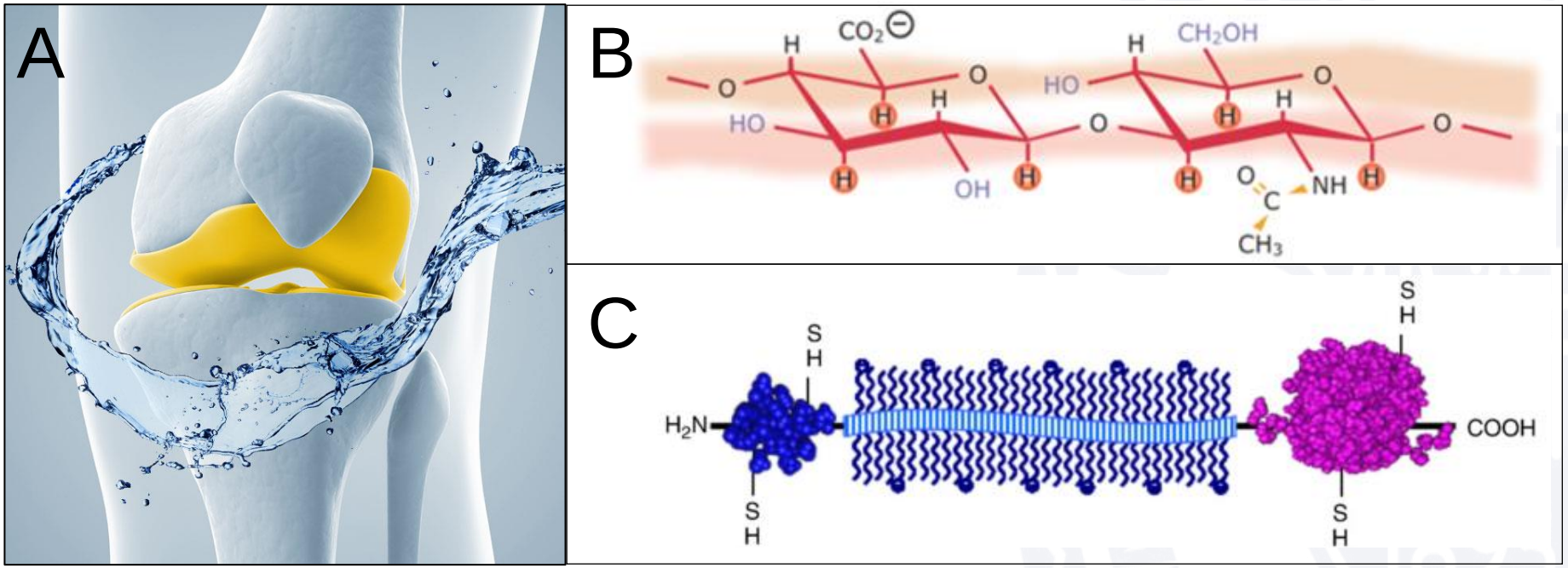
例3 关节滑液



骨骼关节滑液的润滑与抗粘附

透明质酸HA：自然界中保湿性最好的物质

润滑素蛋白Lub：独特精巧结构，两端疏水、中间强负电荷

传感器应用：抗粘附表面仿生构建

Bioinspired anti-adhesion

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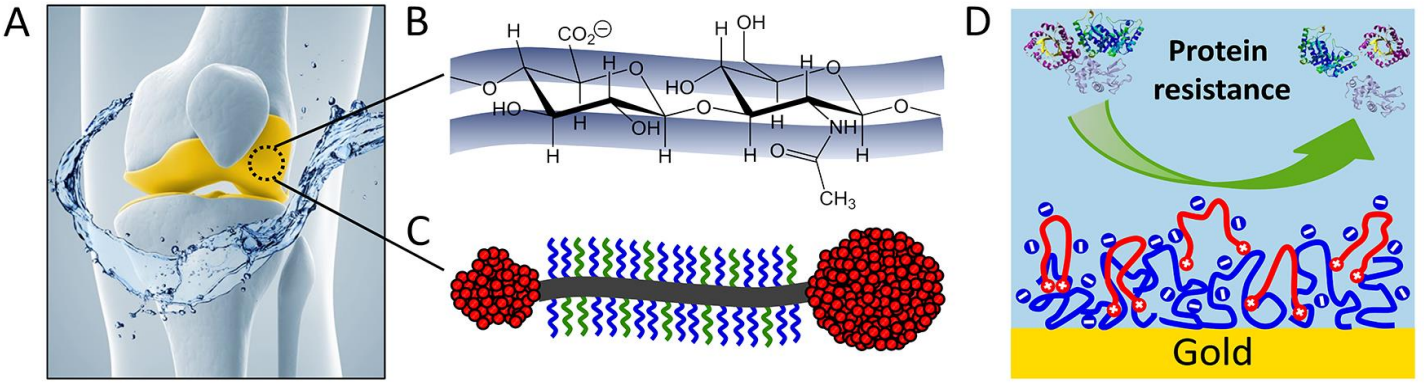
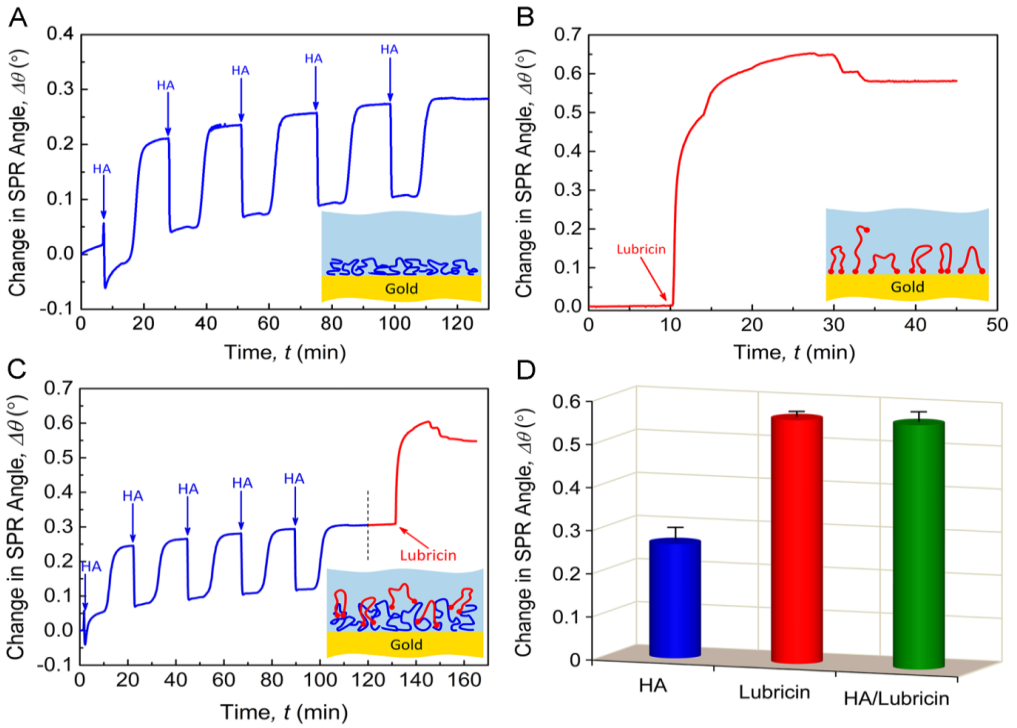


Wren Greene
Deakin Univ

Tannin Schmidt
Univ Connecticut

在线修饰HA、LUB
联合修饰



Su RX, et al. ACS Applied Materials & Interfaces, 2019, 11: 18090-18102*

Bioinspired anti-adhesion

仿生界面抗粘附

GDCh Communications Angewandte International Edition Chemie

Antifouling Coatings

International Edition: DOI: 10.1002/anie.201808987
German Edition: DOI: 10.1002/ange.201808987

Biomimetic Bottlebrush Polymer Coatings for Fabrication of Ultralow Fouling Surfaces

Yinqiang Xia[+], Vahid Adibnia[+], Renliang Huang, Frederic Murschel, Jimmy Faivre, Guojun Xie, Mateusz Olszewski, Gregory De Crescenzo, Wei Qi, Zhimin He, Rongxin Su, Krzysztof Matyjaszewski,* and Xavier Banquy**

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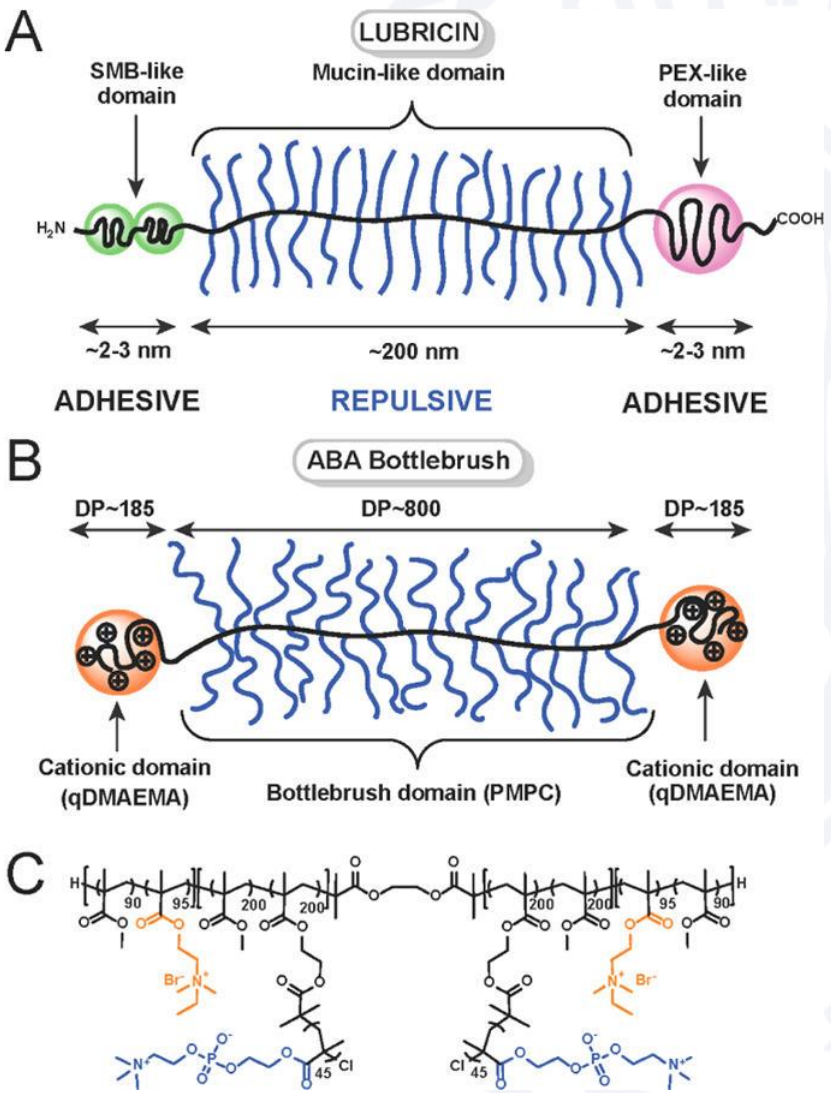

Su RX, et al. Angew Chem, 2019, 58: 1308-1314*

环状两性聚合物刷仿生设计与抗粘附层构建

Krzysztof Matyjaszewski
美国工程院院士

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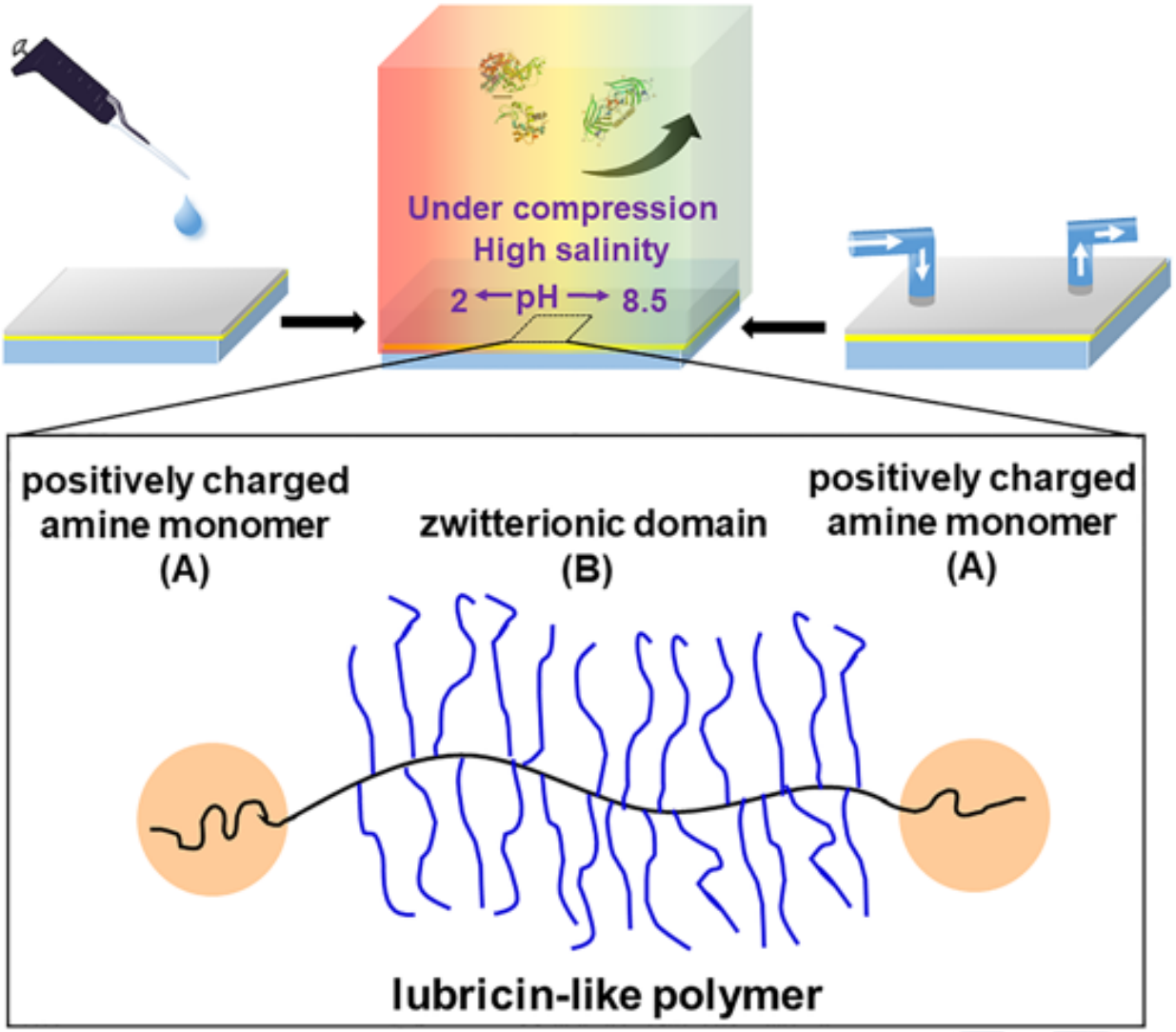

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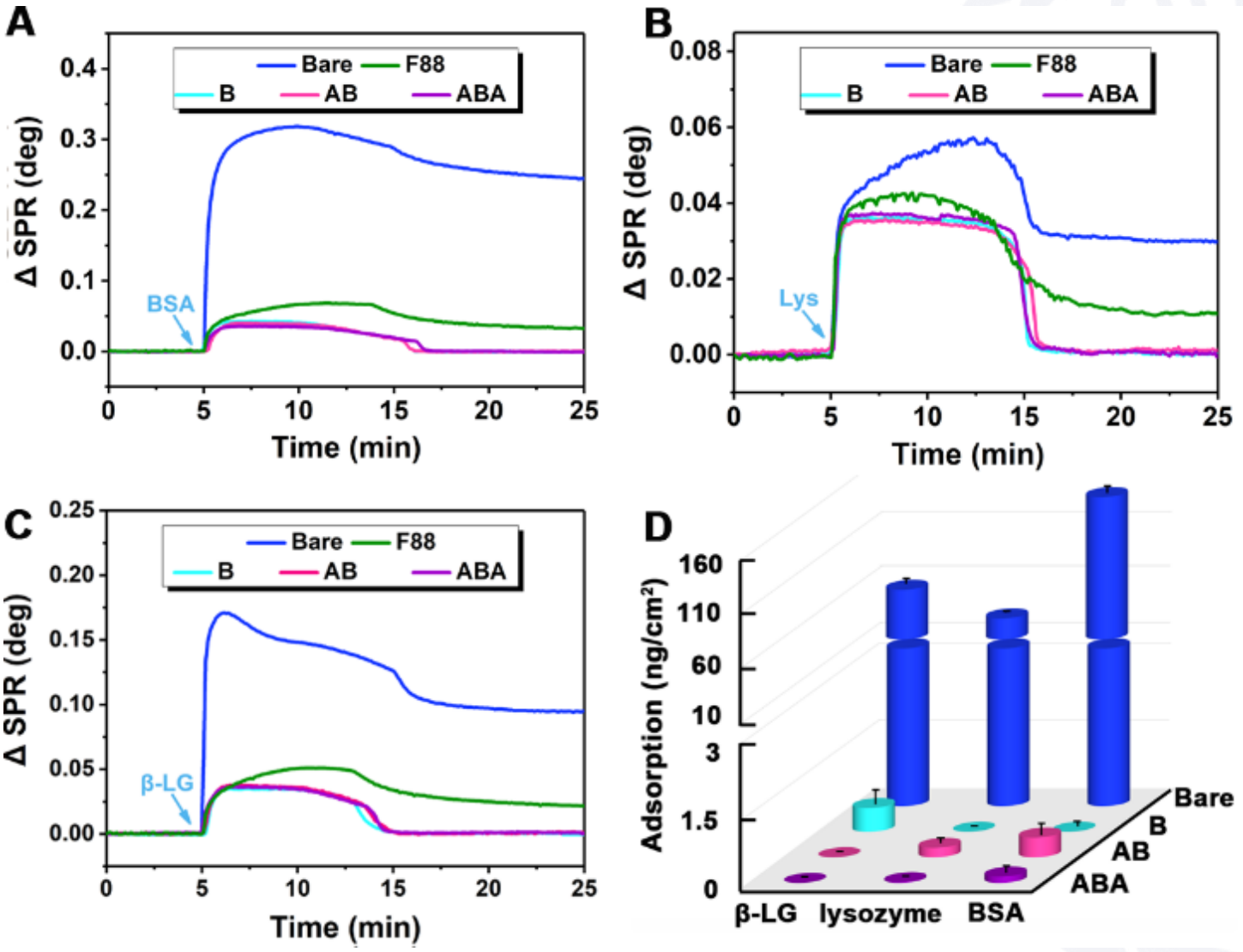

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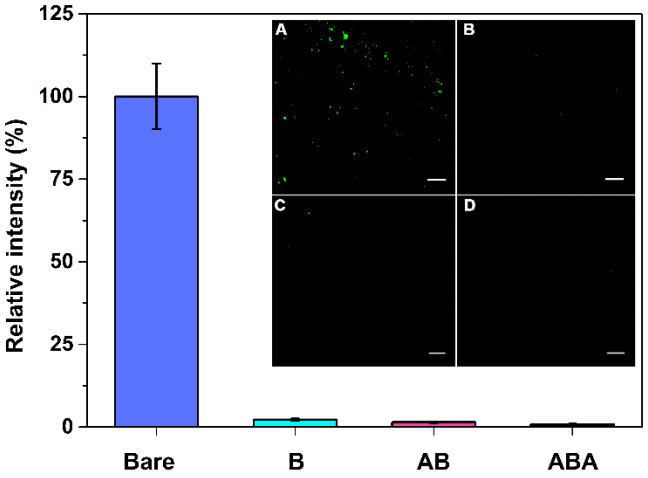
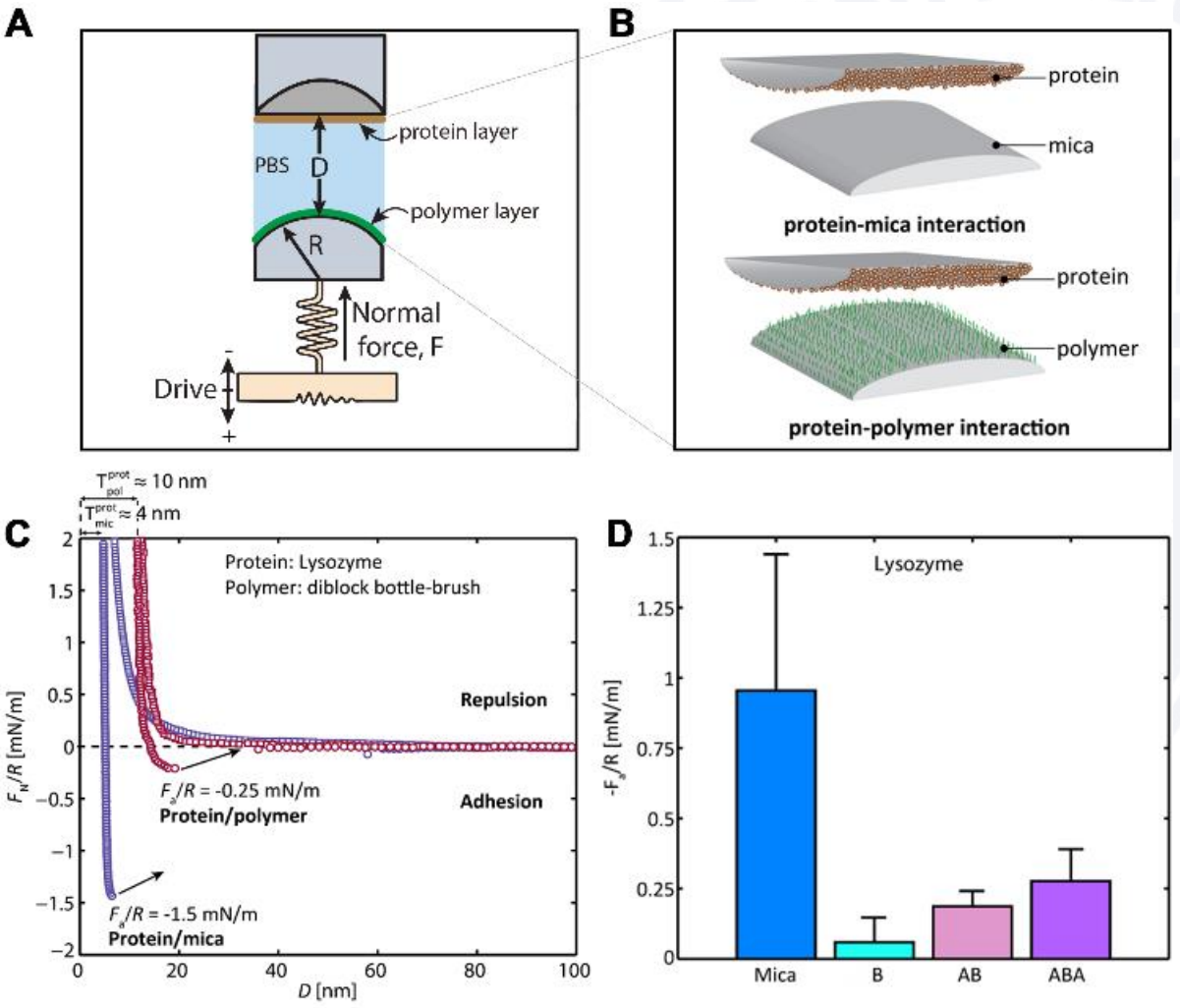


芯片抗细菌吸附性能评价



Su RX, et al. Angew Chem, 2019, 58: 1308-1314*

THANKS

谢谢大家！

欢迎指正和提问！