MICRO-331
Microfabrication technologies

Lecture Finale

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2025 edition

Today's program

- 1st hour:
  - Top-down meets bottom-up (JB)
  - From solid to soft materials microfabrication (YZ)
- 2nd hour:
  - Q&A

New Opportunities for Ancient Materials: a brief overview of silk materials in microengineering

Outline

1. Introduction
   - Biomaterials for bioengineering: benefits and requirements;
   - Unique properties of silk fibroin;
   - Silk transformation, functionalization and fabrication

2. Biomanufacturing of silk materials
   - Ion-/electron-beam lithography;

2. Summary and Discussion

*Prior knowledge & relevant courses:
- Microfabrication technologies (NEMS/MEMS)
- Soft microsystems processing and devices
- Introduction to bioengineering
- Biomaterial engineering

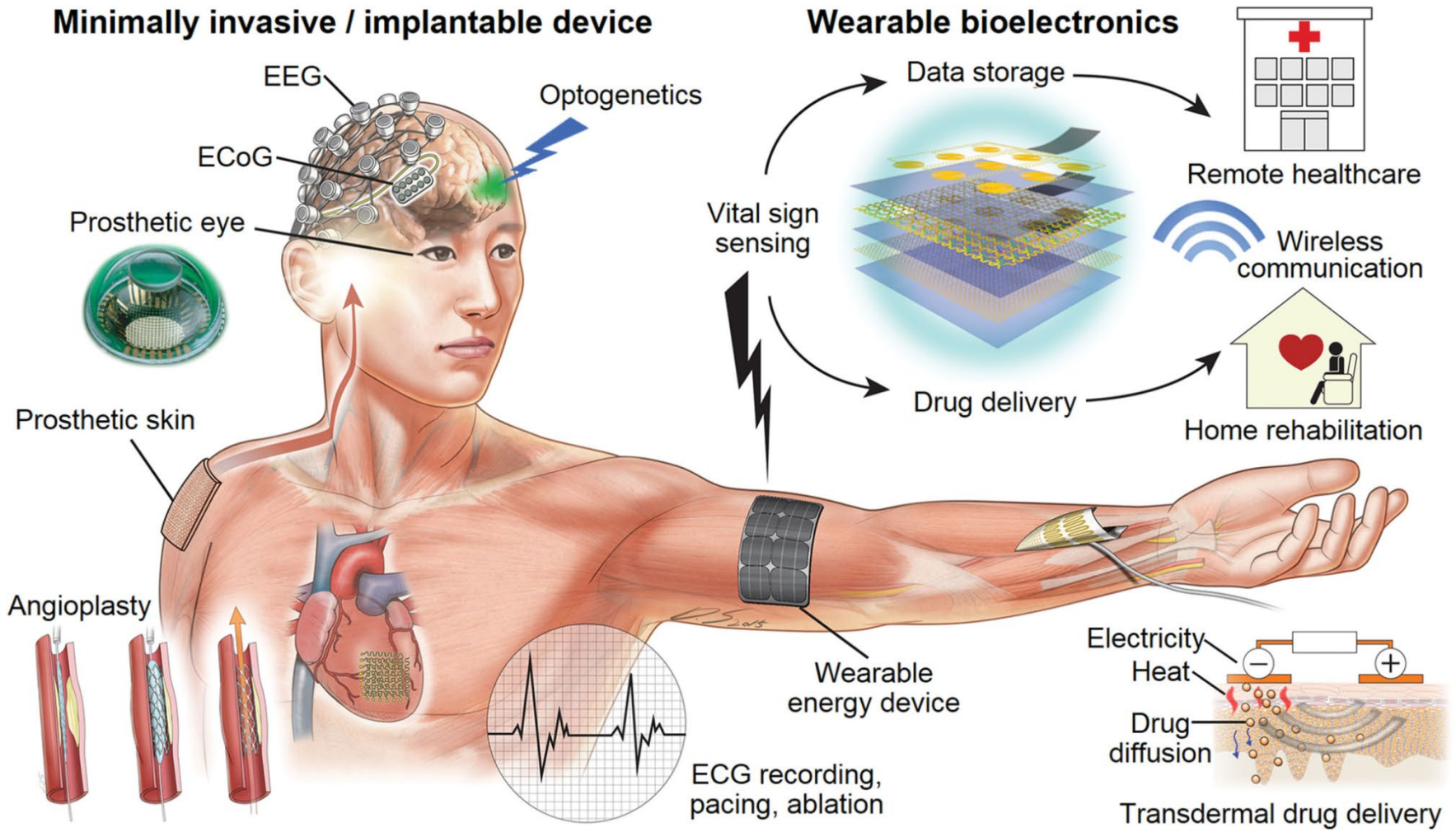
Human-machine interface (HMI)

- Huge benefits in personalized healthcare and rehabilitation
- From wearable devices to direct interface: high signal-to-noise ratio, multiple modalities, direct treatments (drug release)…
- Some examples:

Biocompatibility

1. Suitable mechanical properties: Young's modulus (softness) and inertia (bending stiffness)
2. Non-toxicity (none biochemical mismatch)

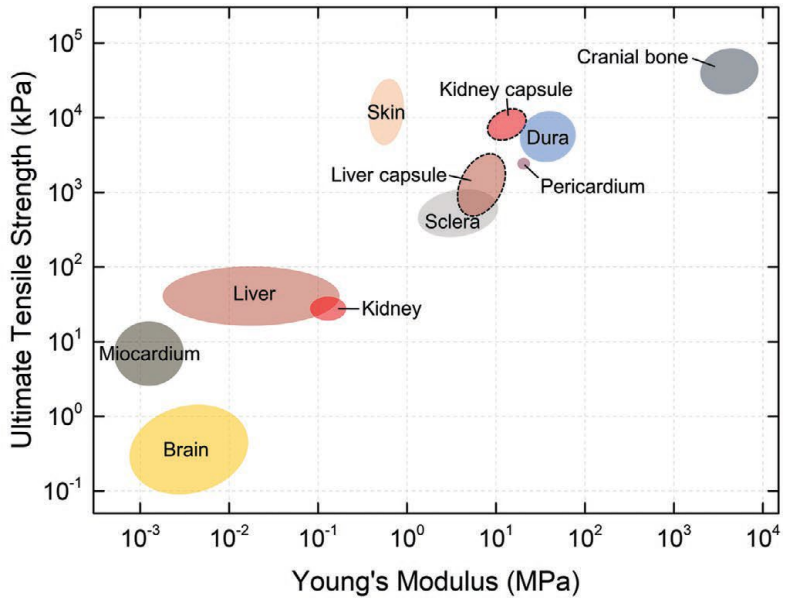
Functionalization (e.g., electronics) and Manufacturing

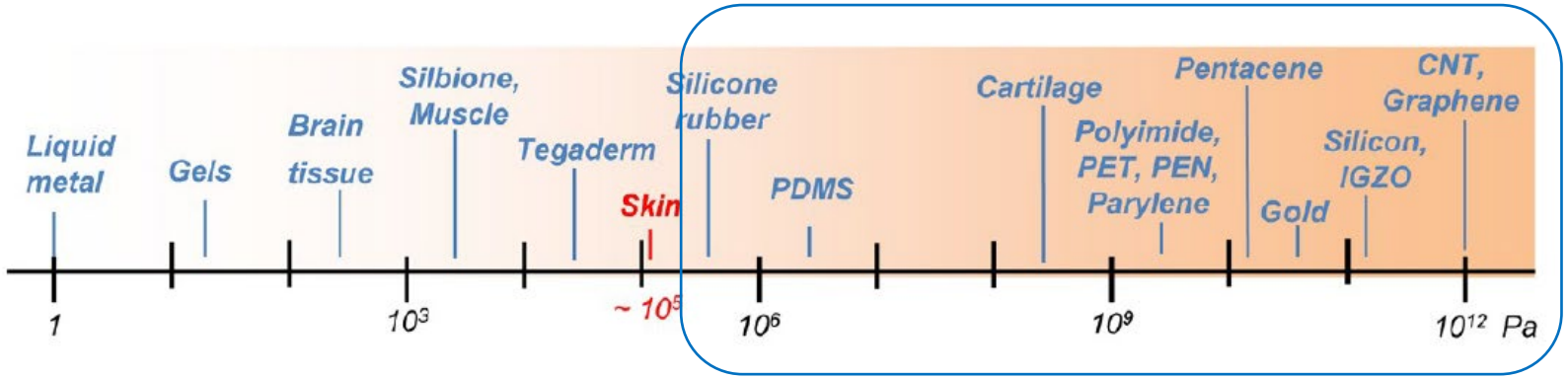


Adv. Mater. 2016, 28, 4203–4218.

First requirement: biocompatibility

1. Suitable mechanical properties: Young's modulus (softness) and inertia (bending stiffness)



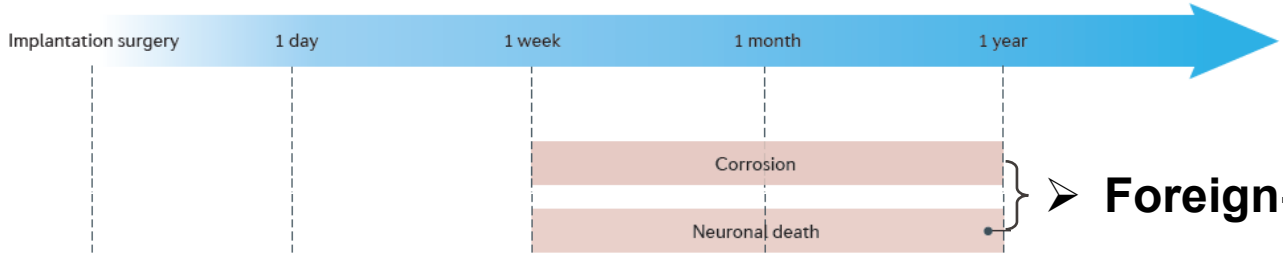


Inertia ∝ Thickness^3

➢ Conventional materials: make it thin!

*Low inertia (bending stiffness), more flexible—easy to deform along with tissues

2. Non-toxicity (none biochemical mismatch)



➢ **Foreign-body response**

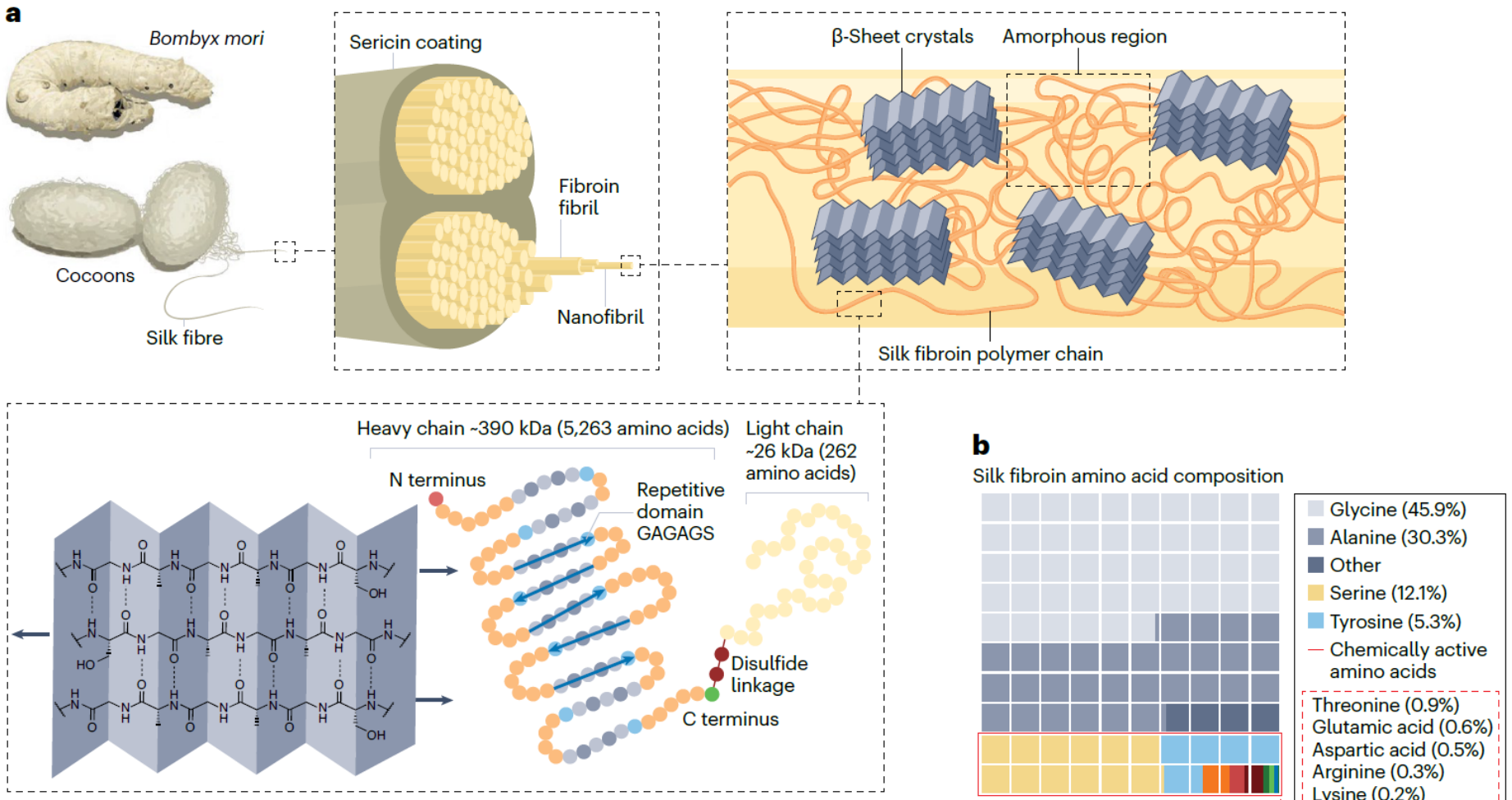
➢ Failure modes of neural probes manifest as a loss of neural recording capability

Adv. Mater. 2020, 32, 1907478; *ACS Nano* 2017, 11, 9614−9635; *Nat. Rev. Mater. 2017,* 2, 1-16.

Common polymers used in microtechniques

- Photoresist = {Polymer + Solvent + Photoinitiator}
  - Polyimide (PI), PMMA, SU-8 …
- PET, rubber, resin…
- Polydimethylsiloxane (PDMS)
- Biopolymers: Cellulose, proteins…

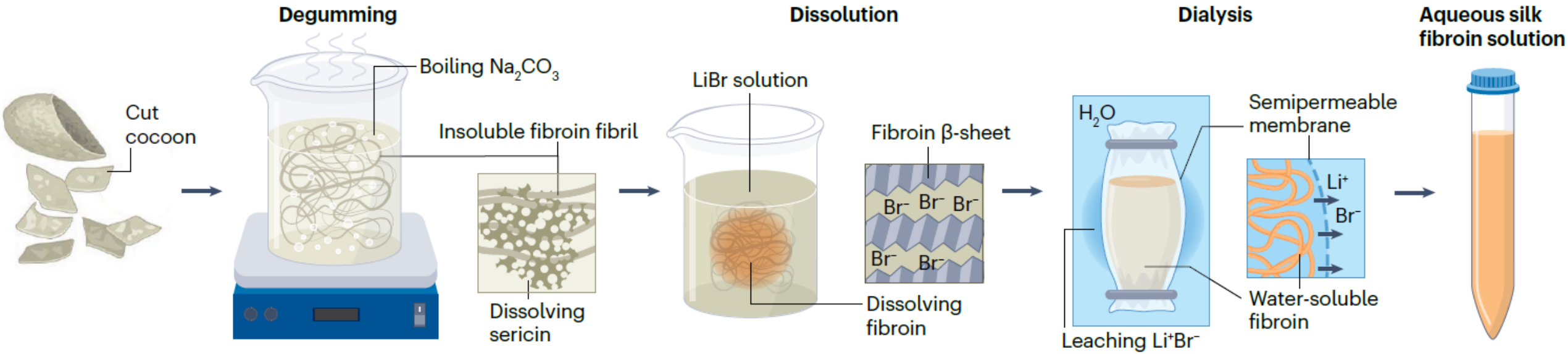
Silk fibroin: a natural, eco-friendly, and biocompatible protein



1. Suitable mechanical properties: tunable from brain to bone
2. Nontoxic, biodegradable, and *edible*

Nat. Rev. Chem. 2023, 7, 302-318.

Silk transformation

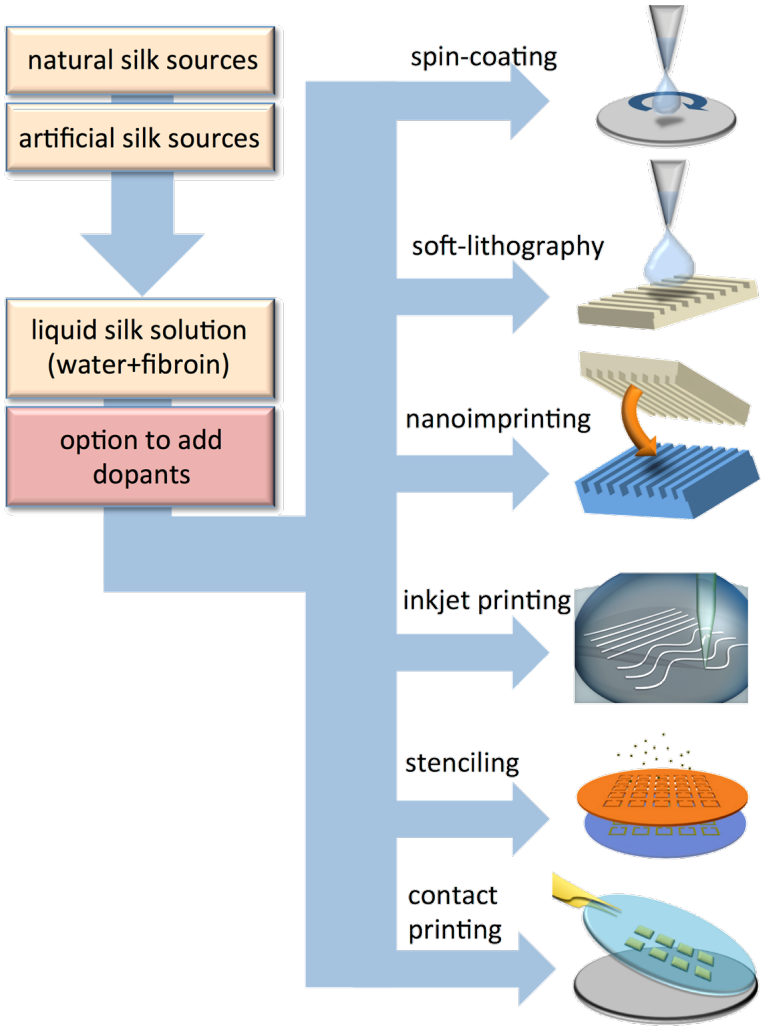


Extraction of silk fibroin from cocoons by removal of sericin protein (degumming) and dissolving in lithium bromide (LiBr) solution to disrupt the H-bonding and to facilitate dissolution. The salt content is removed by dialysis to generate a regenerated silk fibroin solution.

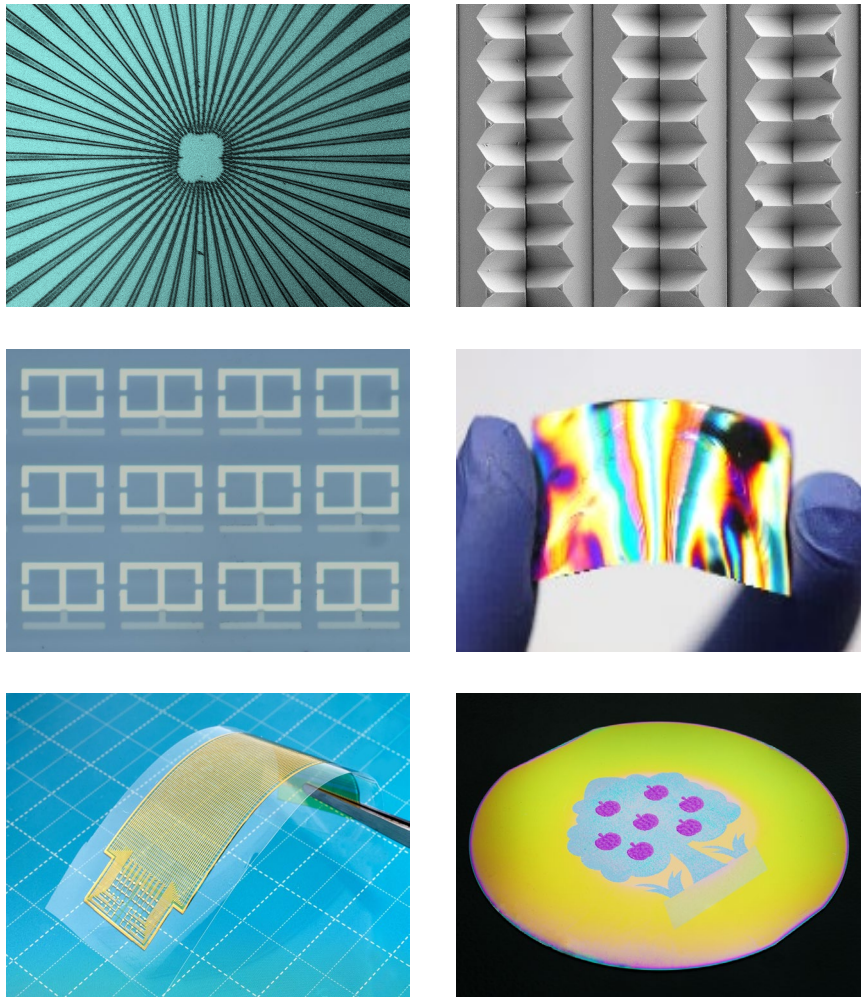
Nat. Rev. Chem. 2023, 7, 302-318.

Engineering the Future of Silk Materials through Advanced Manufacturing

➢ Biomaterial engineering



➢ Soft material fabrication technologies



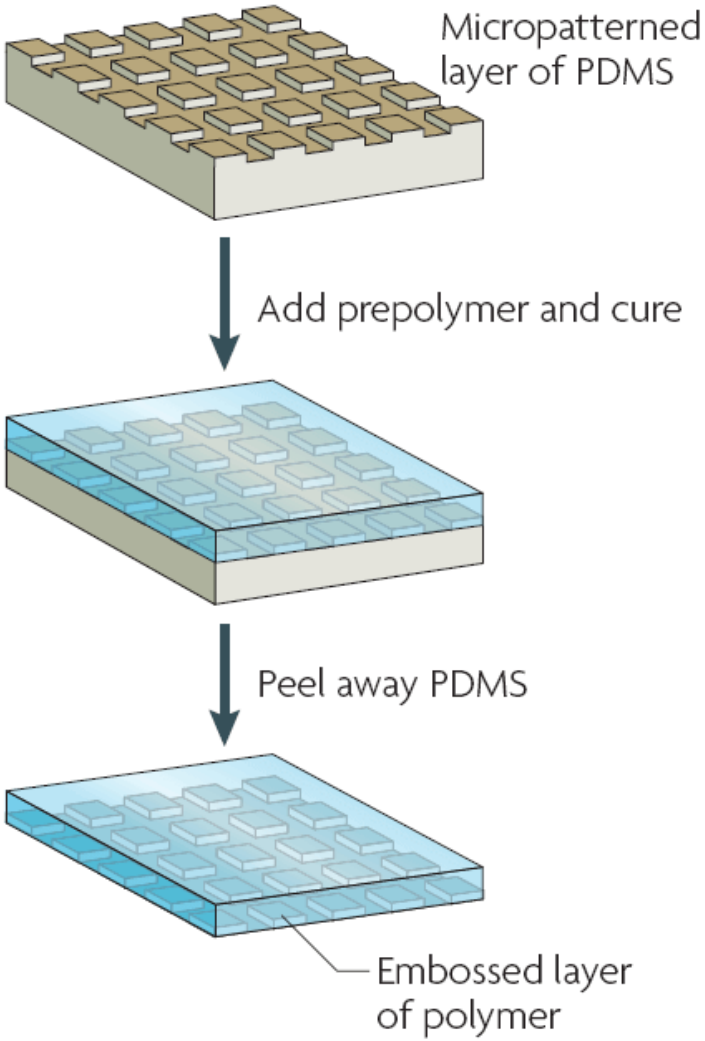
➢ Bioengineering applications

- Photonics
- Electronics
- Iontronics
- Metamaterials
- Skin devices
- Implantable devices
- Brain-machine interfaces
- …

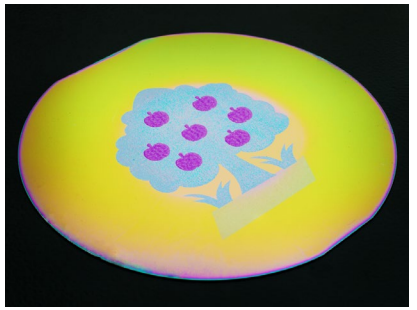
Adv. Mater. 2012, 24, 2824-2837.

Two simple examples

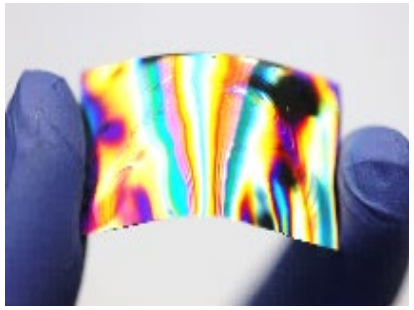
- Replica molding



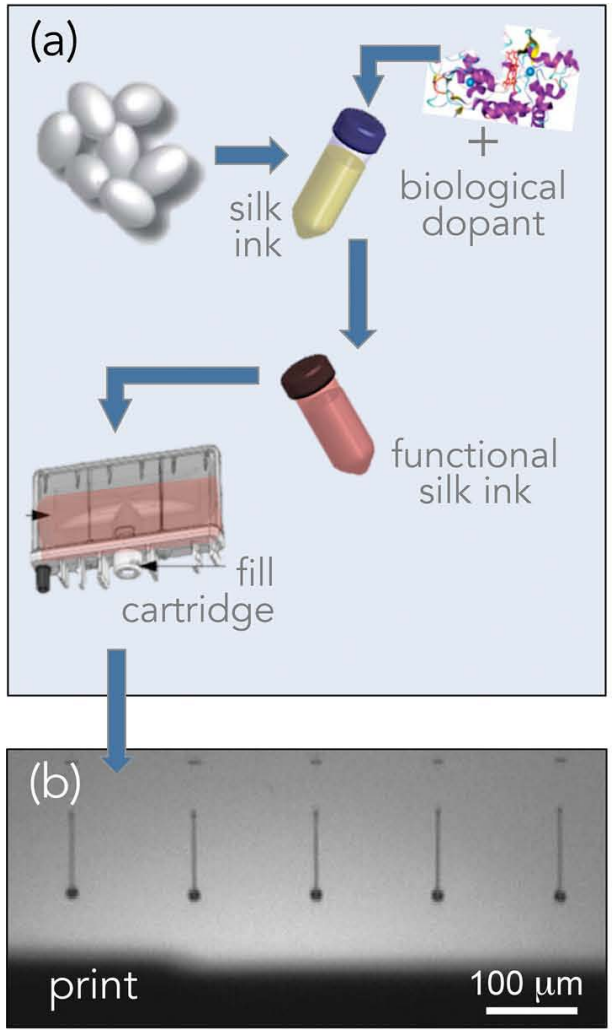
- Large-scale silk pattern



- Silk/metal grating

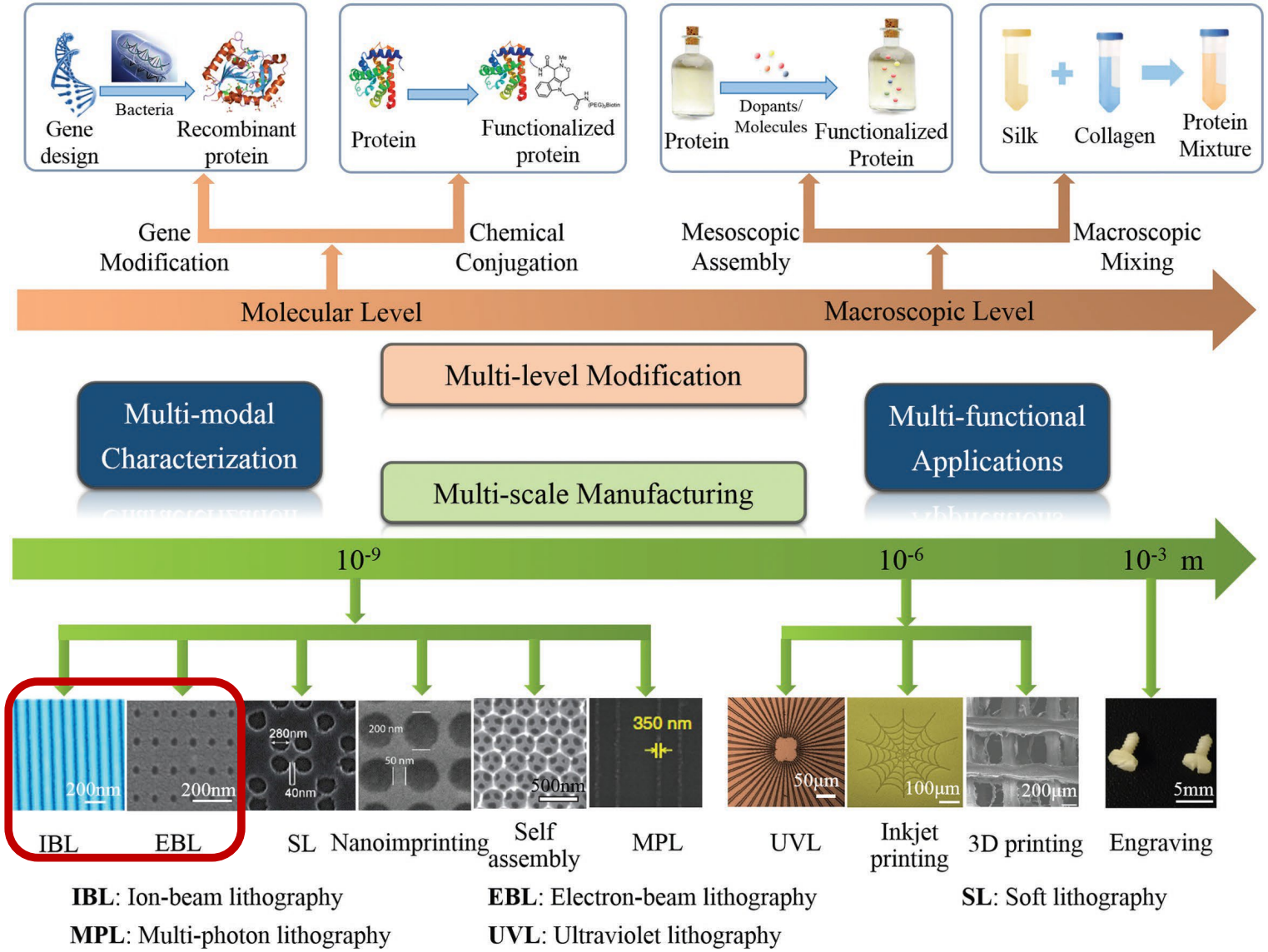


- Ink-jet printing



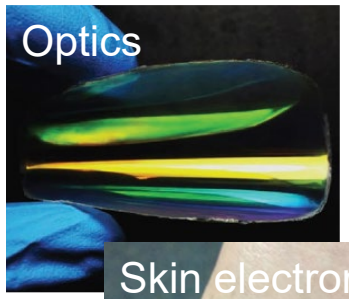
Adv. Mater. 2015, 27, 4273–4279; Small 2018, 1802050; Small 2018, 1802953;

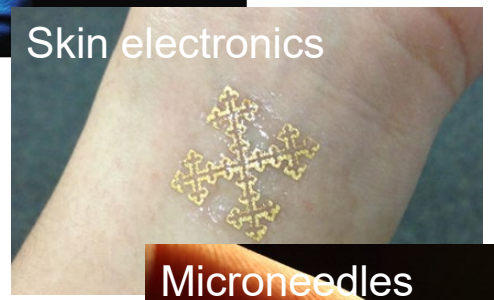
Silk functionalization and fabrication



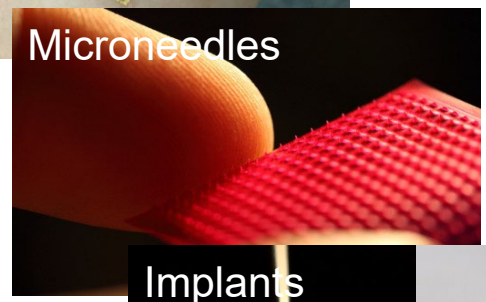
IBL: Ion-beam lithography **EBL**: Electron-beam lithography **SL**: Soft lithography

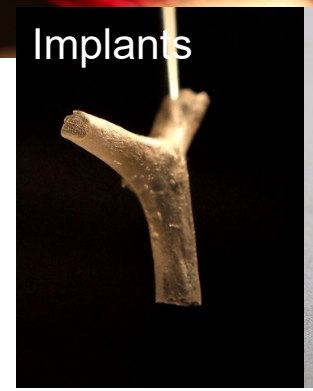
MPL: Multi-photon lithography **UVL**: Ultraviolet lithography





22 Tasty and Delicious Egg White Recipes You Must Try

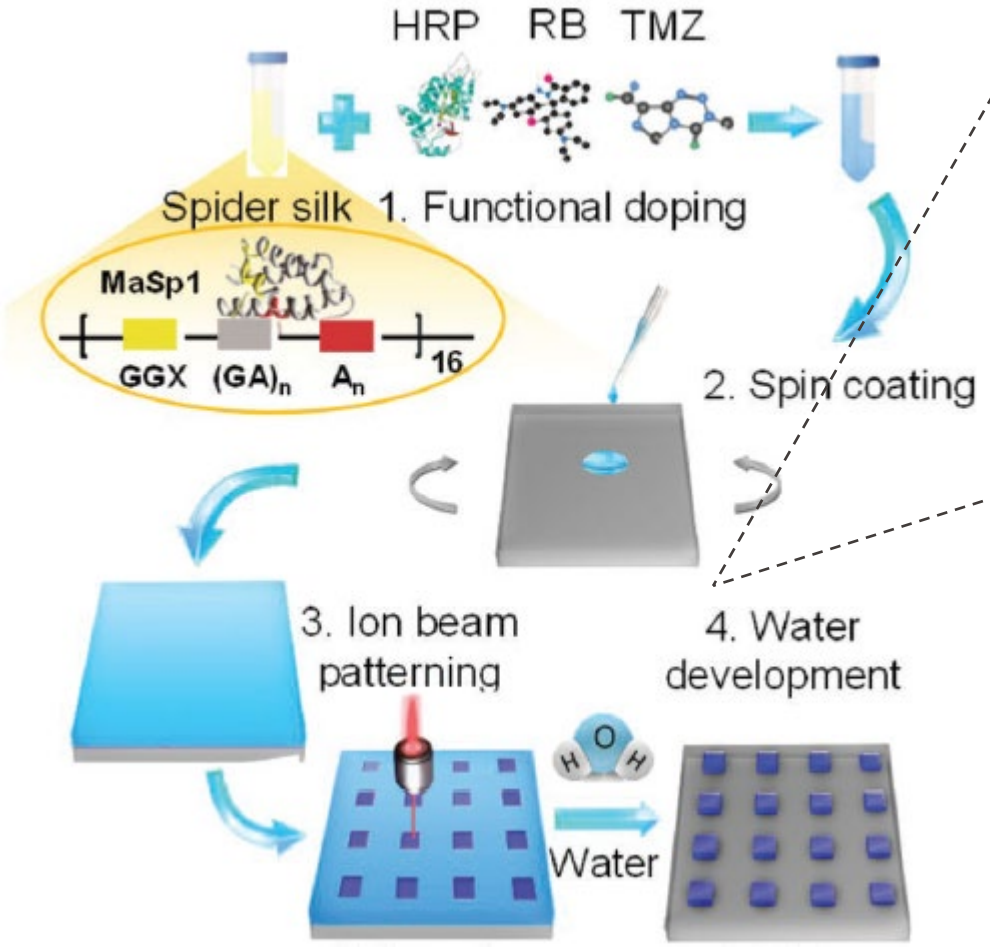




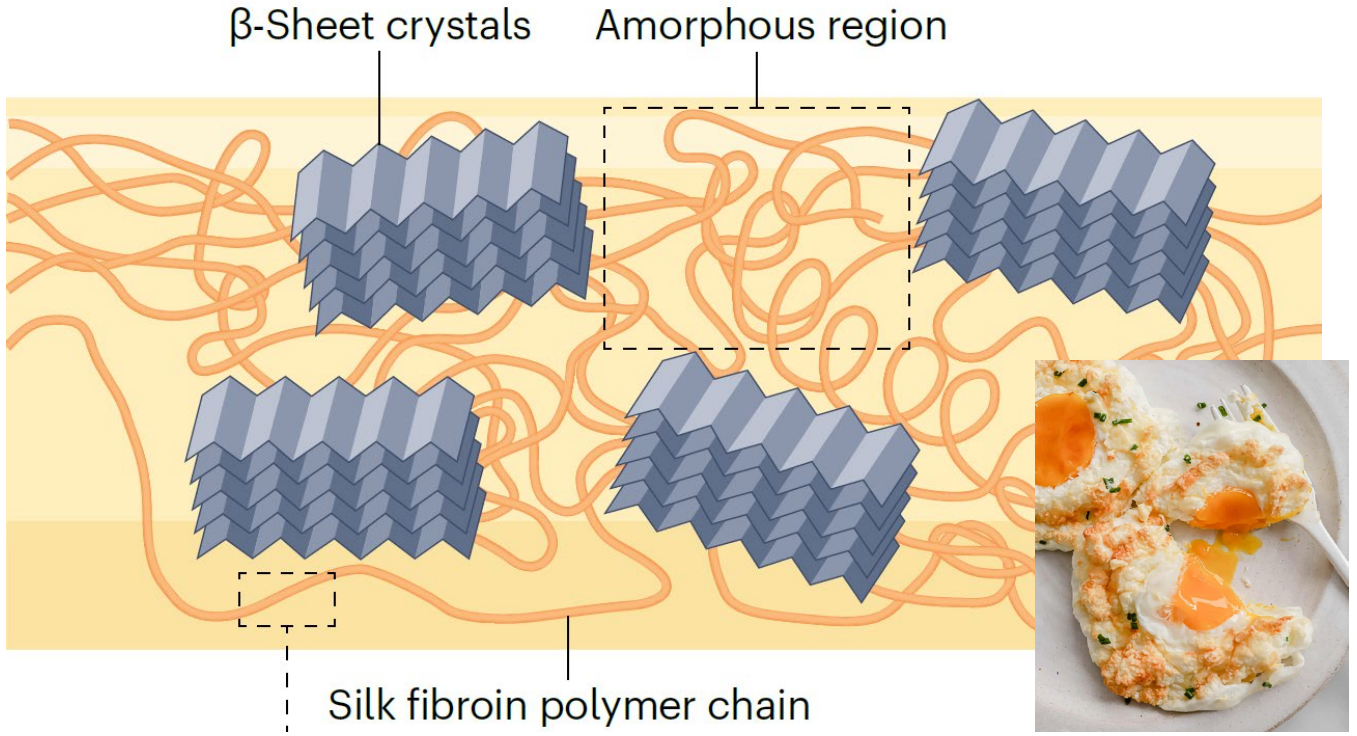
Adv. Mater. 2018, 30, 1706983.

An example: Ion-/electron-beam lithography

- Direct writing
- Silk as the resist polymer—eco-friendly and biocompatible



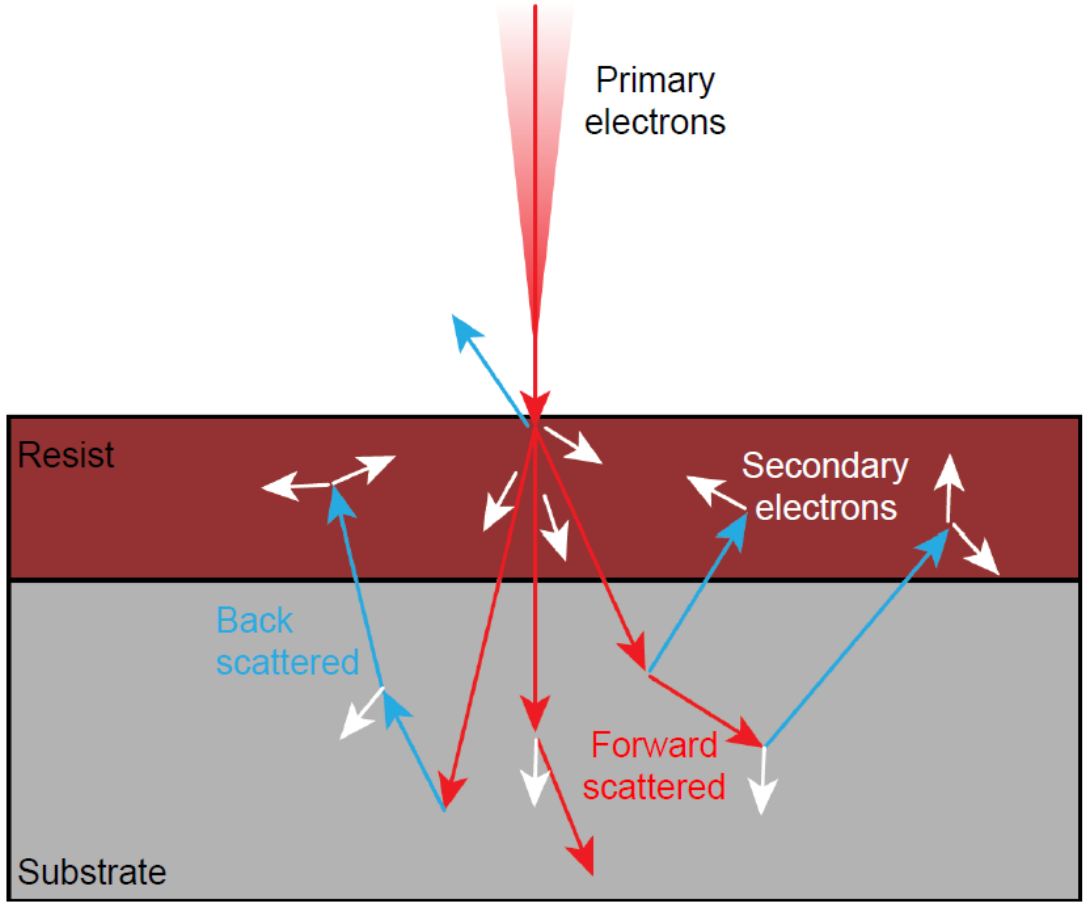
- A quick reminder: the secondary structures of silk materials
  - Insoluble in water
  - Soluble in water

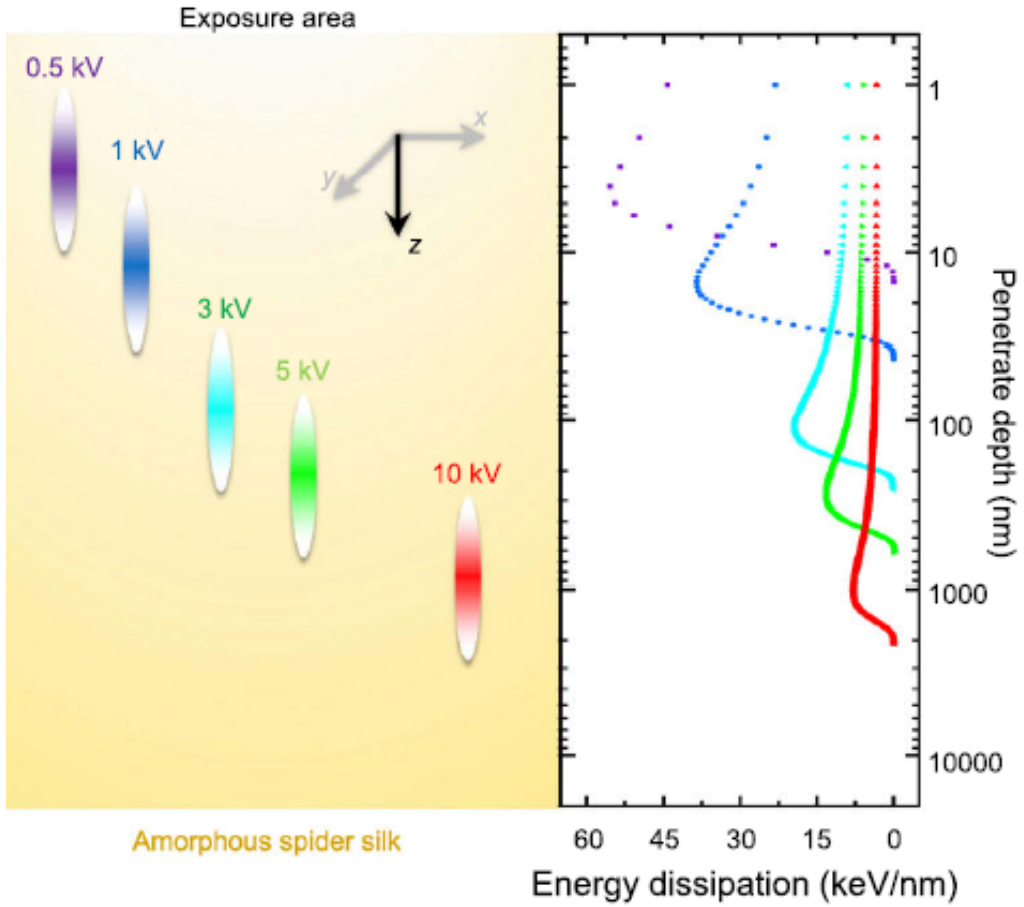


Adv. Mater. 2018, 30, 1705919.

Difference of ion- and electron-beam lithography

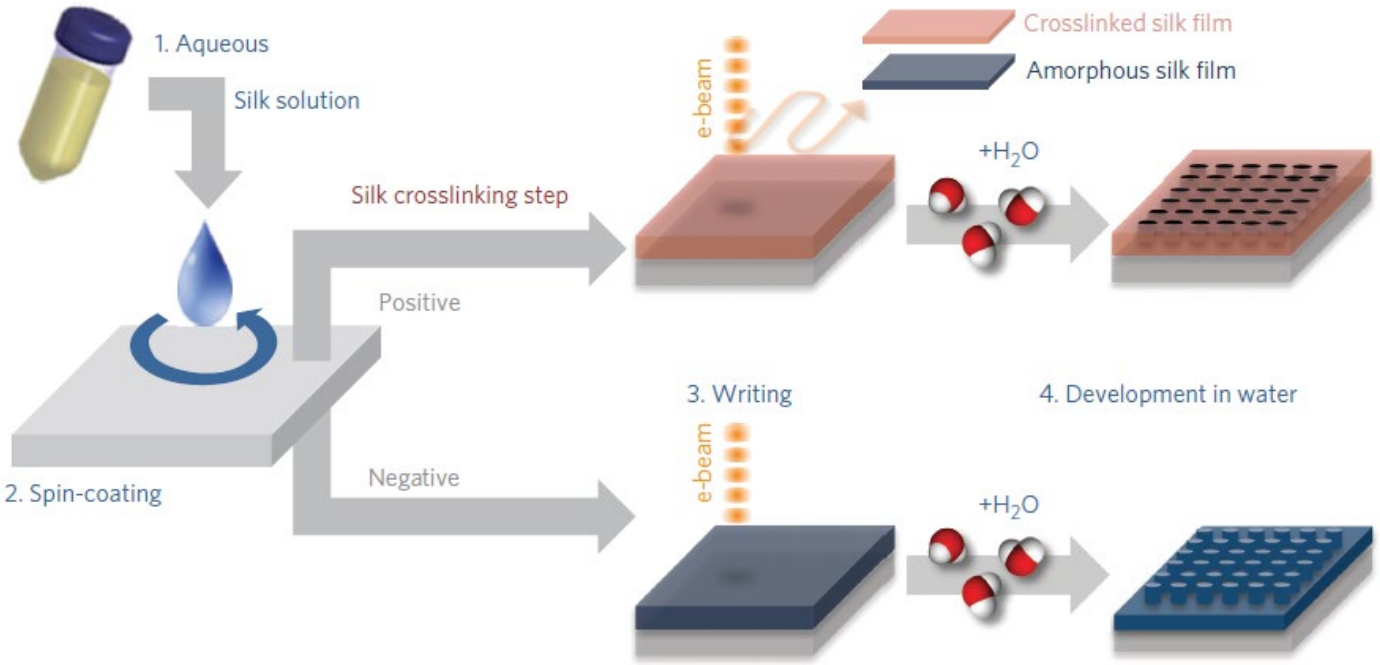
- Ion-beam lithography: heavy ions & more direct interaction with silk → from top to bottom
- Electron-beam lithography: tunable penetration in silk with different exposure energy → from middle/bottom to top

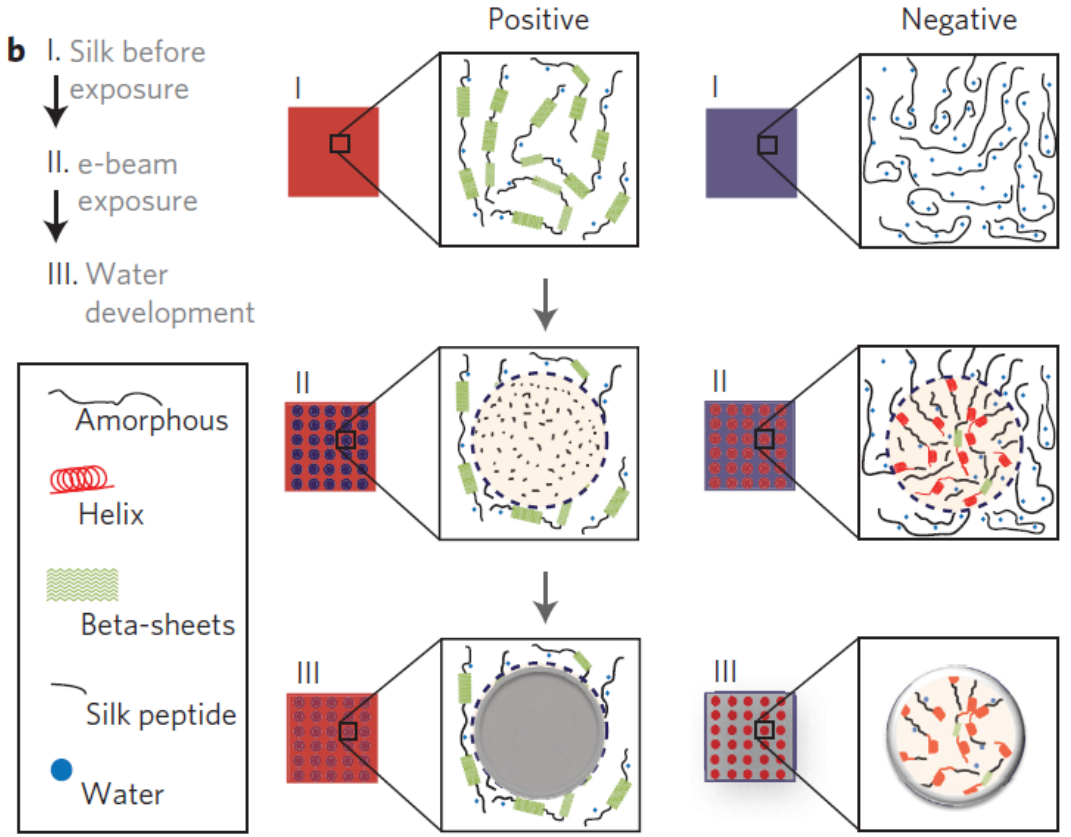




Nat. Commun. 2021, 12, 5133.

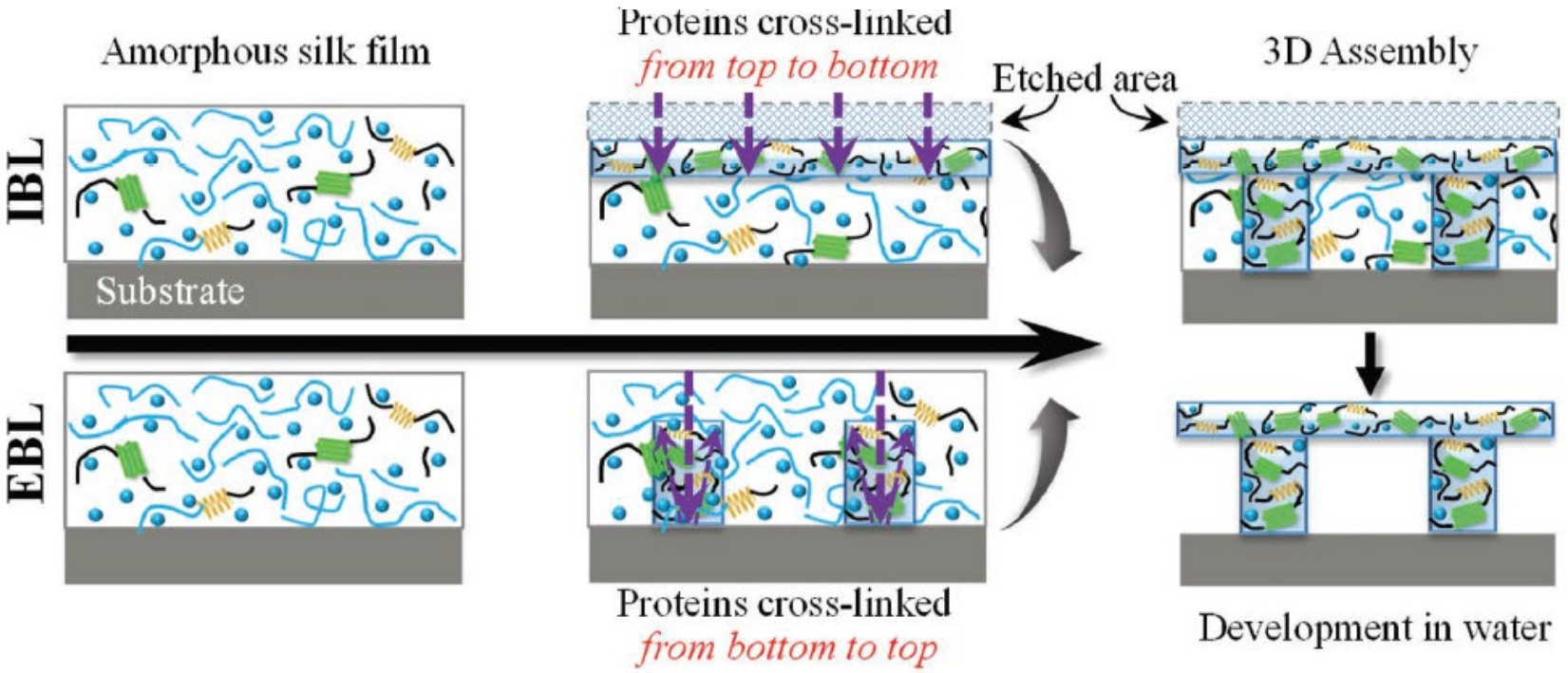
Effect of EBL on silk polymorphism

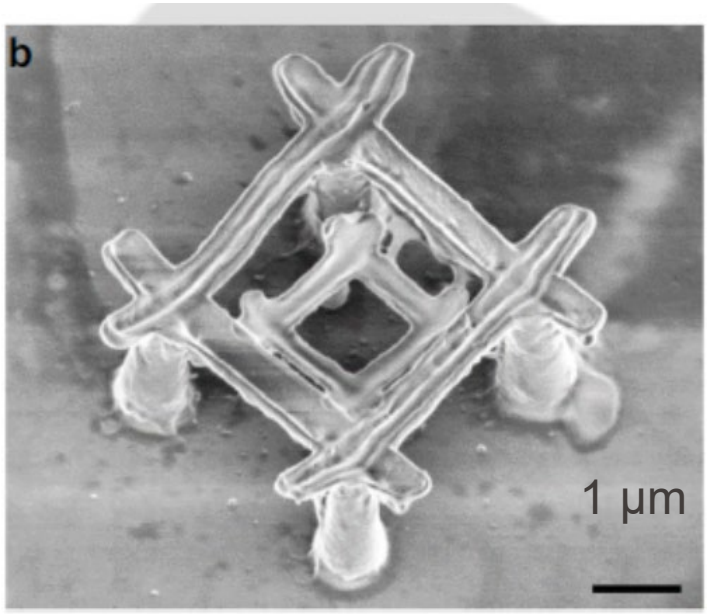




Manufacturing of 3D nanoarchitectures

- Combining IBL and EBL

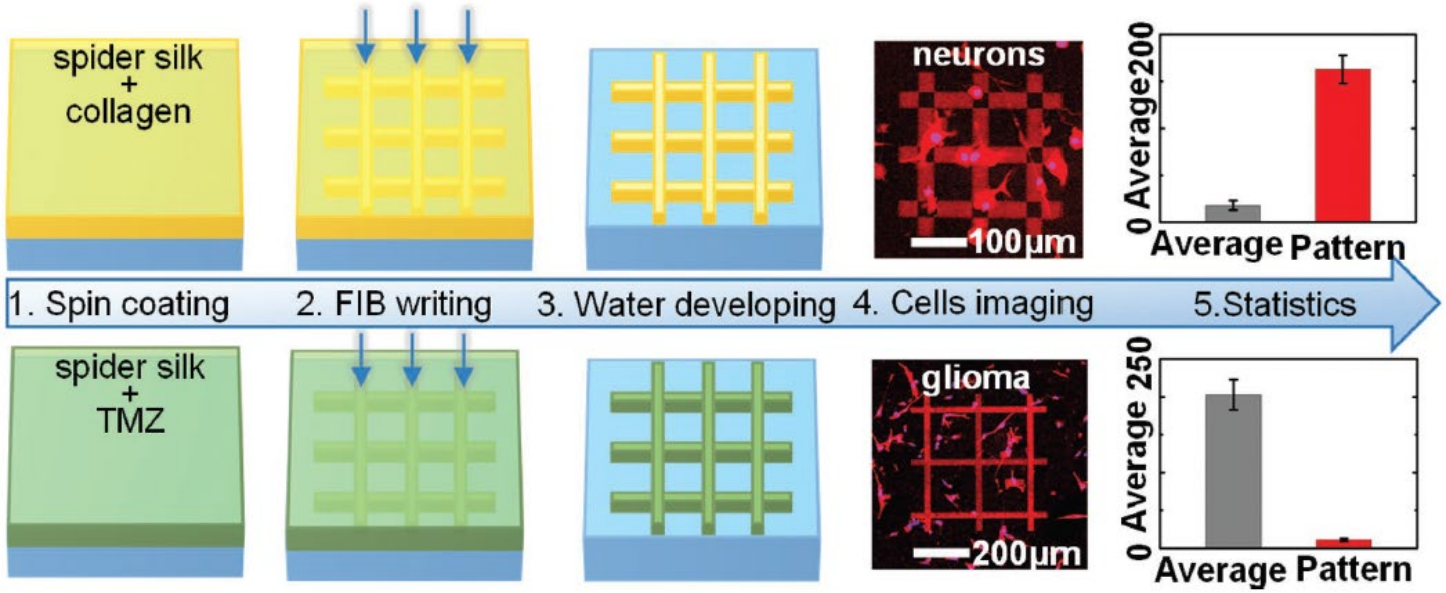




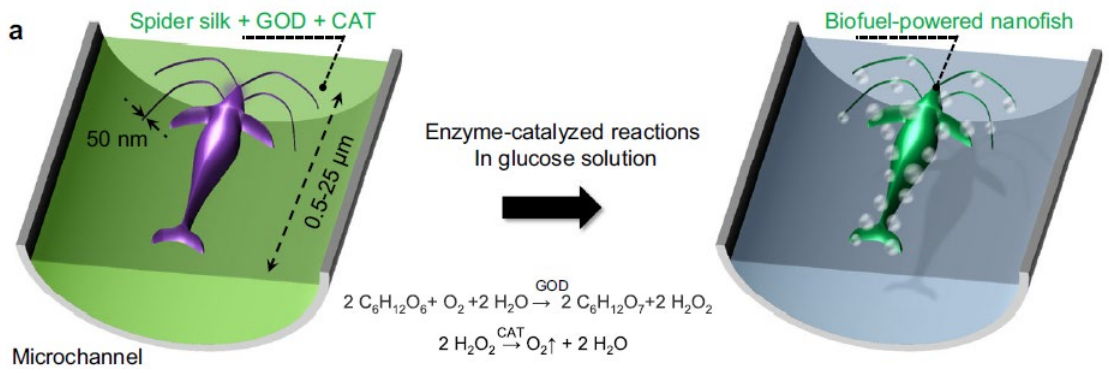
Adv. Mater. 2018, 30, 1705919.

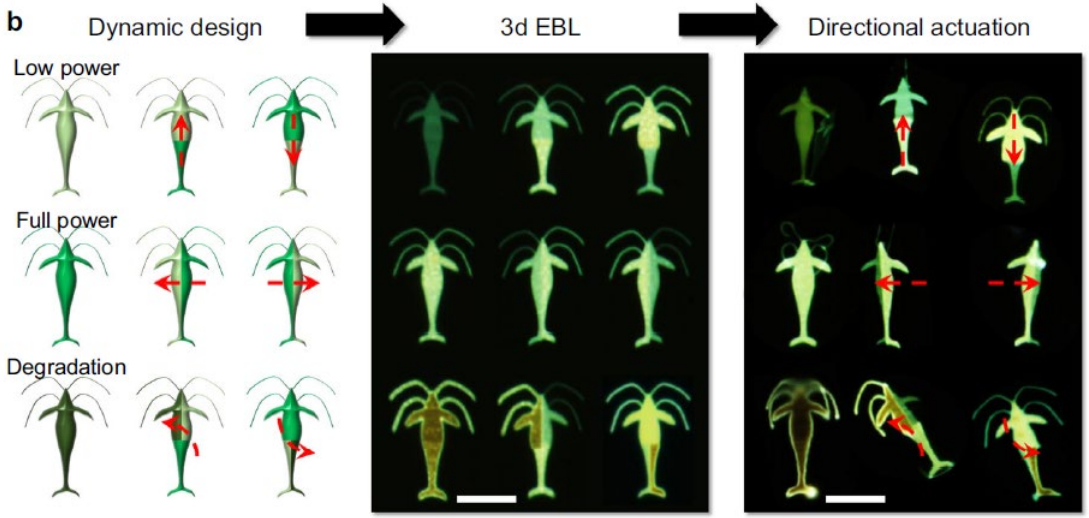
Applications of the patterned silk structures

- Functionalization of silk nanostructures for cell culture



- Fabrication of silk-based nanorobots





Adv. Mater. 2018, 30, 1705919; *Nat. Commun.* 2021, 12, 5133.

Take home messages

- **Biomaterial engineering** and **microfabrication techniques** have offered various opportunities to **silk**—an ancient material on earth—in the area of **bioengineering and microengineering**.
- *The possibilities are only limited by our imaginations*.

*Further reading list:
Introduction video:
https://youtu.be/vqqWw3xkMzA

Silk chemistry:
Nat. Rev. Chem. 2023, 7, 302-318.
Silk manufacturing:
Adv. Mater. 2018, 30, 1706983.
Other applications:
Adv. Energy Sustainability Res. 2021, 2, 2100035.

Other information for preparing the final exam

- **Please read the Moodle page for all information**
- SLT results are good.
- New updates:
  - Guide for SLT questions
  - Exam rules (final) and some suggestions
  - ‘Cheat sheet template'

Two more Q&A slots on January 14, 8 to 10 am & January 15, 8 to 10 am

Please email us to book in advance (before January 13)

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