2020

Photolithographic micropatterning of organic, flexible biomaterials and its applications

Sayantan Pradhan
Virginia Commonwealth University

Sayantan Pradhan

Meng Xu

Vamsi K. Yadavalli

Photolithographic micropatterning of organic, flexible biomaterials and its applications

Sayantan Pradhan, Meng Xu, Vamsi K. Yadavalli

Department of Chemical and Life Science Engineering, Virginia Commonwealth University, Richmond, VA

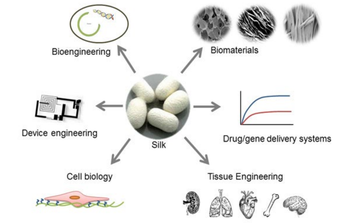
Introduction

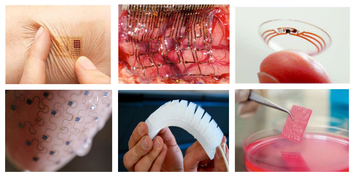
The ability to form biodegradable, biocompatible and flexible sheets with microarchitectures using robust and high throughput techniques such as photolithography finds application in areas of therapeutics, bio-optics and bioelectronics.

Silk protein obtained from silkworms is a potential candidate for the realization of such devices due to lucrative intrinsic properties such as- availability, biodegradability, biocompatibility, processability etc.

The combination of silk protein with conductive polymer PEDOT:PSS enables the realization of conductive architectures on flexible substrates which finds application in flexible bioelectronics.

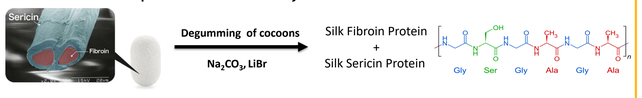
Kirigami-inspired cuts can engineer flexibility in materials through the creation of patterned defects. Silk kirigami films can be fabricated using photolithography for functional biointerfaces and flexible bioelectronics.



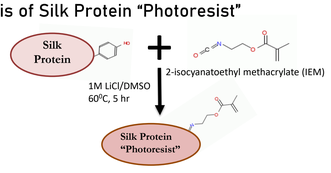


Methods

- Extraction of silk protein from *Bombyx mori* silk cocoons

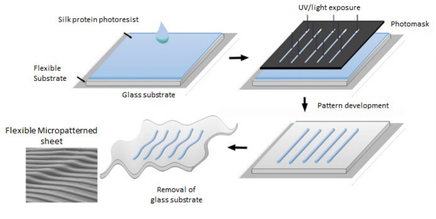


- Synthesis of Silk Protein "Photoresist"



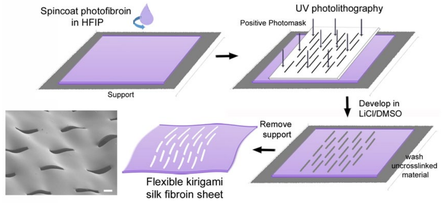
- Isocyanate addition occurs at the amino acid nucleophilic centres (OH, NH_2, COOH)
- Sericin: **74.1%** of residues
  Fibroin: **21.3%** of residues
- The product is precipitated in cold ethanol and washed using 1:1 mixture of ethanol and acetone before lyophilisation.

- Fabrication of silk microstructures on flexible silk fibroin films



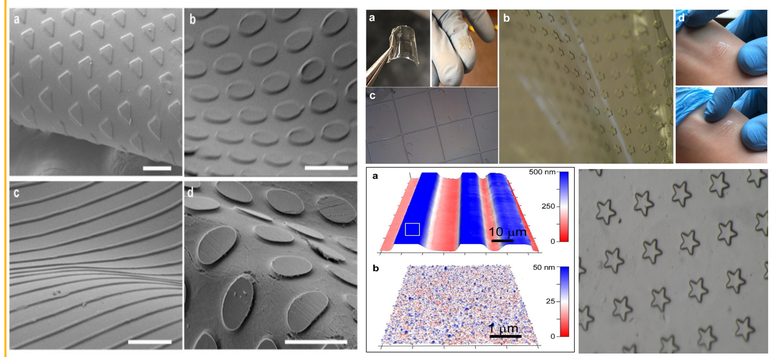
- Casting the silk protein ink on the substrate to form a film of desired thickness
- Exposing the ink under UV light through a photolithographic mask to crosslink exposed areas
- Development of patterns by dissolving the uncrosslinked areas using a appropriate solvent

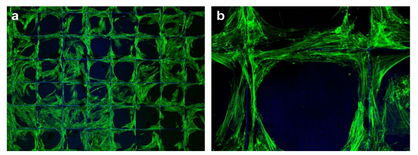
- Fabrication of "Silk Kirigami" films with patterned defects



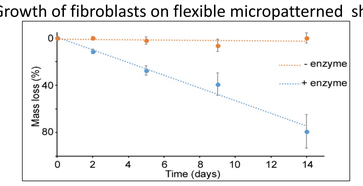
Results

Silk protein microarchitectures on flexible silk fibroin films



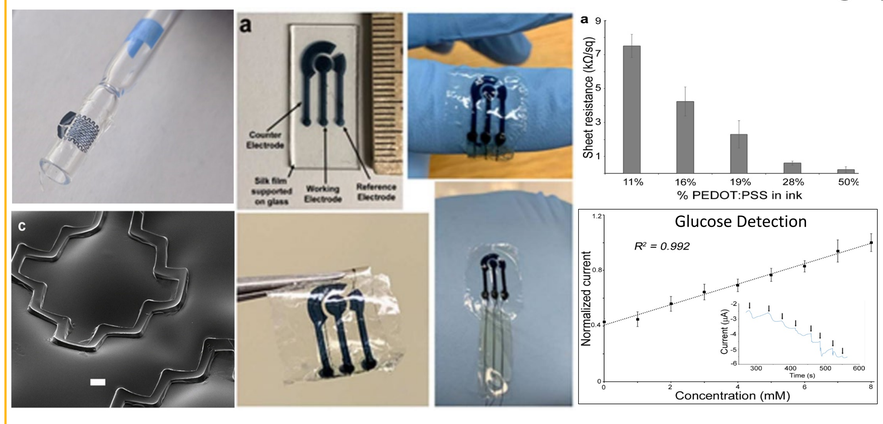


Growth of fibroblasts on flexible micropatterned sheet

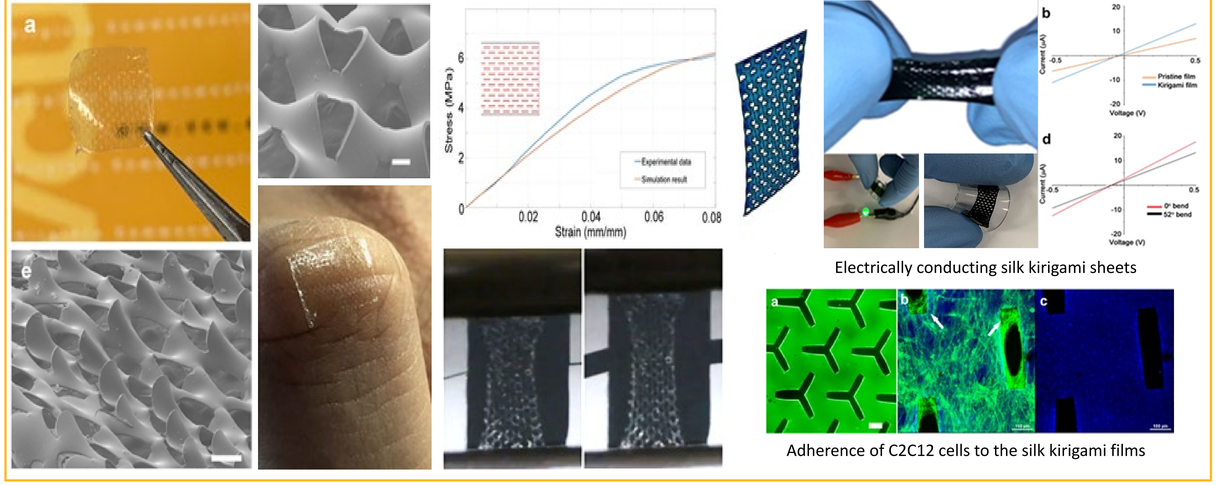


Proteolytic degradation of fibroin substrates *in vitro*

Conductive silk structures on flexible films and sensing applications



Biofunctional silk kirigami with engineered properties

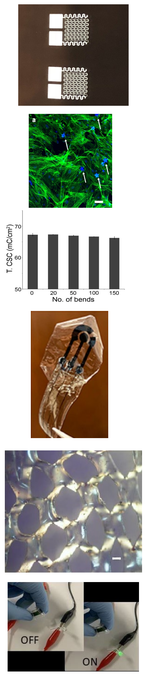


Electrically conducting silk kirigami sheets

Adherence of C2C12 cells to the silk kirigami films

Discussion

- Photolithography is a simple, well developed, scalable, high throughput, high resolution and low cost microfabrication technique
- The micropatterned films are robust and can be bent to any conformation without any delamination of the structures due to the *vinyl linkage* between substrate and patterns
- Micropatterned 2D silk fibroin sheets can be used as substrates for cell adhesion and proliferation wherein the microstructures act a template for directed cell growth
- The Silk Sericin Photoresist provides a stable, biocompatible and biodegradable matrix for entrapping conducting polymers such as PEDOT:PSS and polyaniline and immobilizing enzymes
- Biosensing is demonstrated through the detection of electrochemically active (Ascorbic acid) and non-electrochemically active (glucose) targets
- Stretchable silk fibroin film with tuneable mechanical properties inspired from "kirigami"- the Japanese art for paper cutting, can be fabricated using photolithography
- Such patterned defects generate remarkable "self-shielding" leading to engineered elastic behavior and deformation
- Micropatterned cuts can also increase the conformability of films to soft biological interfaces
- Furthermore, by combining them with conducting polymers flexible, intrinsically conductive sheets were fabricated
- Unique properties of silk kirigami suggest a host of applications as transient, "green", functional biointerfaces, and flexible bioelectronics



References

[1] M. Xu, **S. Pradhan,** F. Agostinacchio, R. K. Pal, G. Greco, B. Mazzolai, *et al.*, "Easy, Scalable, Robust, Micropatterned Silk Fibroin Cell Substrates," *Advanced Materials Interfaces,* vol. 6, p. 1801822, 2019.

[2] **S. Pradhan,** K. M. Moore, K. M. Ainslie, and V. K. Yadavalli, "Flexible, microstructured surfaces using chitin-derived biopolymers," *Journal of Materials Chemistry B,* vol. 7, pp. 5328-5335, 2019.

[3] R. K. Pal, **S. Pradhan**, L. Narayanan, and V. K. Yadavalli, "Micropatterned conductive polymer biosensors on flexible PDMS films," *Sensors and Actuators B: Chemical,* vol. 259, pp. 498-504, 2018/04/15/ 2018.

[4] M. Xu, Y. Jiang, **S. Pradhan,** and V. K. Yadavalli, "Use of silk proteins to form organic, flexible, degradable biosensors for metabolite monitoring," *Front. Mater. 6: 331. doi: 10.3389/fmats,* 2019.

[5] **S. Pradhan,** L. Ventura, F. Agostinacchio, M. Xu, E. Barbieri, A. Motta, *et al.*, "Biofunctional Silk Kirigami With Engineered Properties," *ACS Applied Materials & Interfaces,* vol. 12, pp. 12436-12444, 2020/03/18 2020.

Acknowledgements

➢Dr. Ramendra K. Pal
➢Dr. Yanke Jiang
➢Dr. Antonella Motta

➢NSF-CBET# 1704435