Gordon Conference on Nano Fabrication

Silk: A top down approach for protein micro- and nano structures

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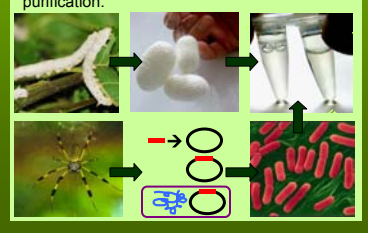
Silk features

- Green, all aqueous, and ambient condition processing
- Programmable biodegradability
- Biocompatible, FDA approved
- Remarkable optical and mechanical properties
- Patternable down to the nanometer scale
- Doping with bioactive species

Origins and processing of silk fibroin

- Silk fibroin from B.*mori cocoons* or genetic recombinant material.
- All aqueous dialysis based extraction and purification.



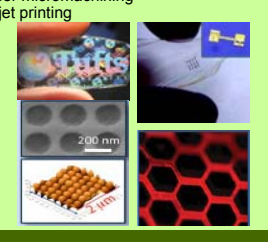
Materials formation

- Controlling water content
- Controlling crystallinity (beta sheet content)

⟶ Formation of films, gels, foams, fibers etc.

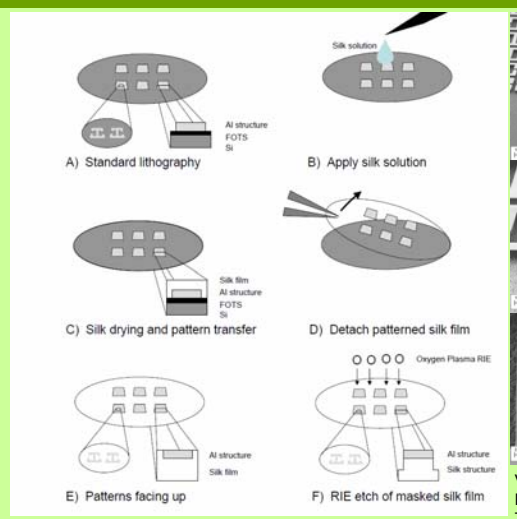
Devices and fabrication

- Optical and photonic devices with nm size features (nanoimprinting)
- Silicon on silk electronics
- Microfluidics
- Laser micromachining
- Inkjet printing

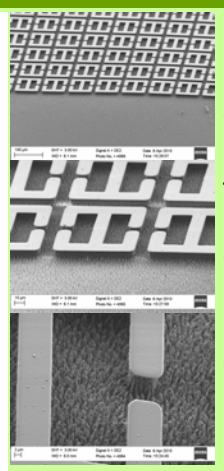


Fabrication – Providing additional functionality to silk protein by adding structure to the material with the following fabrication techniques:

- RIE, Lift off, Embossing, and Molding



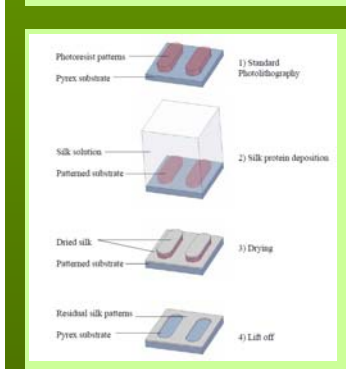
Silk RIE fabrication scheme



Various magnifications of RIE fabricated Al on silk THz resonance antennas.

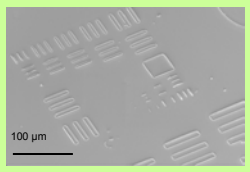
Reactive Ion Etching

- Novel metal (Al, Au) masking transfer technique
- RIE patterning of protein films
- Fabrication of THz resonance antennas in silk

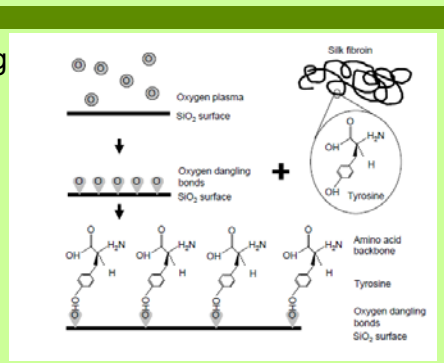


Silk lift off fabrication scheme

Lift off – Patterning silk fibroin protein/ SiO_2 - bioorganic/ inorganic interface



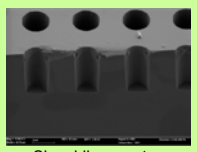
USAF silk on SiO_2 pattern



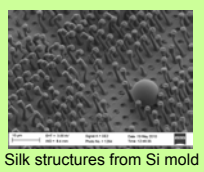
Silk/ SiO_2 adhesion model

Molding - Single step process

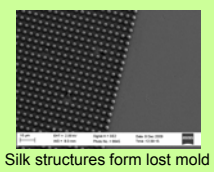
- Dry adhesion
- Hydrophobic surfaces



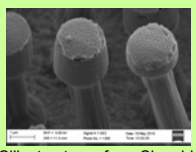
Si molding master



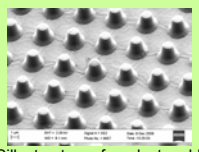
Silk structures from Si mold



Silk structures form lost mold

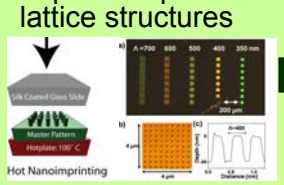


Silk structures from Si mold (magnified view)



Silk structures from lost mold (magnified view)

Nano imprinting - Fluorescent enhancement of doped silk photonic lattice structures



Previously established by Amsden et al. and Mondia et al.

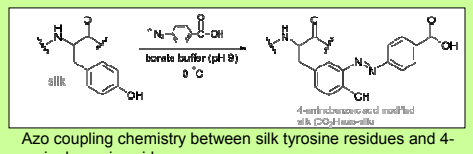
New silk materials – Providing additional functionality to silk protein material by:

- Genetic alteration
- Chemical modification

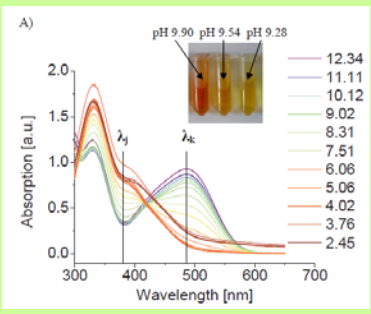
Genetic material synthesis (Green Fluorescent Silk Protein)

(Preliminary test with silk/ GFP blend)

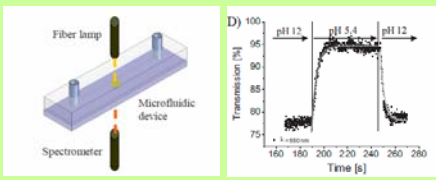
Chemical material synthesis (diazonium functionalization)



Azo coupling chemistry between silk tyrosine residues and 4-aminobenzoic acid.



Colorimetric response of the azo silk to pH changes.



Incorporating azo silk in an optofluidic micro system to measure the time response of the material.

Fusion – Combining new silk materials and fabrication techniques to create fluorescent enhancement photonic lattice GFP silk structures.

GFP silk photonic lattices: Optical excitation at 495 nm and emission signal collected at 510 nm.

Future – Structurally enhanced and genetically encoded protein materials bio sensors.

Summary

- Fabrication techniques are potentially scaleable to nm size features.
- Broad scheme of silk material alteration allows to generate novel biomaterials with unprecedented combination of functions.
- Combination of nano structures and genetically encoded materials could potentially enable a new generation of all protein based devices.

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References: ·A. Murphy, et al. Biomaterials 2008, 29, 2829 · K. Tsioris et al. Adv.Func.Mater. 2010, 20, 1 · C. Bettinger et al., Adv.Mater. 2007, 19, 2847· J. Mondia et al. Adv.Mater. *in press* · J. Amsden et al. Adv.Mater. 2010, 22, 1–4 · Dae-Hyeong Kim et al. Nature Materials *in press* · G. Altman et al. Biomaterials 2003, 24, 40 · G. Leisk et al. Adv.Mater. *in press.*