Bioinspired fiber–based micro and nanofluidics. Role of X–ray phase contrast imaging

Kostya Kornev
School of Materials Science and Engineering
Clemson University, SC
Nanofluidic applications of nanofiber yarns and webs

- Fiber–based probes:
  - biofluids from salivary glands, microcapillaries, sweat pores, etc..
  - aerosol droplets 1–10 µm
  - gaseous samples by capillary condensation
- Stimuli–responsive fibers

**Challenges:**
Fibers must be highly porous, strong, …
Applications of artificial proboscises

A nanoprobe which will pierce the cells and draw a biofluid from it.
Set up for cells piercing

Medium: Dulbecco's Modified Eagle Medium with 4.5g/L glucose, L-glutamine and sodium pyruvate
Fluorescence imaging of live–dead cells

Magnification 10

Magnification 50
Outline

• Mechanisms of fluid absorption and delivery: lessons from Nature

• Artificial proboscises
What can we learn from Nature?

NSF EFRI: Lepidoptera proboscises as prototypes of multifunctional micro and nanofluidic devices

distributed actuation, sensing, superior flexibility, and maneuverability + superior suction action +…

Courtesy of Dr.P.Adler (1987)
Objectives

- Determine the role of dorsal linkage in feeding process
Feeding from porous materials

Butterflies and moths are often seen on porous substrates like wet soil or dung where they feed to obtain nutrients such as salts and amino acids.
Puddling imitation
X-Ray Phase–Contrast Imaging of Butterfly Intake System and Flows in Artificial Proboscises

Daria Monaenkova
Taras Andukh
Beniyamin Rubin
Sasha Tokarev

Experiments at APS were conducted under the guidance of Dr. Wah-Keat Lee
• Artificial proboscises
Artificial proboscises

Stimuli-responsive fibers and yarns

**Challenges:**

Fibers must be highly porous, strong, and field reactive
Fast flows or flows in insect’s world

0 s $R=228\mu m$

40 $\mu s$ $R=650\mu m$

90 $\mu s$ $R=290\mu m$

3.4 ms $R=230\mu m$
Absorption by trilobal fibers: Hexadecane

Absorbed volume*

- Fiber 1: $d_f=35$ um; $R_d^{**}=93$ um
- Fiber 2: $d_f=43$ um; $R_d^{**}=101.13$ um

*The values of absorbed volume are normalized by the initial volume of the drop, ** Maximum Radius measured from the center of the yarn
Wicking in shaped fibers: X-ray phase contrast imaging

The droplet is smaller than the fiber size

Diameter of the fiber is 650 µm

Big droplet larger than the fiber diameter
Fluid probing and delivery using capillary action

Nanometer pores: high suction pressure ⇒
  + strong driving force for absorption, good retention ability
  - very slow flow

Tens of micrometer pores,
  - low retention ability
  + very fast flow
Challenges

• Visualization of moving menisci and contact lines simultaneously with the feeding droplet (micron and submicron + hundred microseconds resolution)

• Visualization of moving menisci and contact lines at the nanometer scale of nanofibers and nanochannels (100 nm – few micrometers)

• Fast focus switching

• X-ray tomography of hierarchical porous structures and live insects

• IMAGING FLOWS IN SINGLE CELLS
Thank you for your attention!

Acknowledgements:

PhD students: Daria Monaenkova, Taras Andrukh, Sasha Tokarev, Maryana Kovalchuk, Chen-Chih Tsai, Monte Bedford, Vijoya Sa, Yu Gu

HS students: Caleb Clipovitz, Kara Edwards, Campbell Yore, Steven Rea

Post Doc: Dr. Benya Rubin