Biologically Inspired Optical Materials and Devices
Harnessing Nature’s Light Manipulation Strategies for Dynamic Optical Materials

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3.8 billion years

wild, vibrant species diversity

tough scrutiny

There surely are lessons to be learnt ...
Elasticity
Controlled deformation

An acrobatic octopus

Source: Nova - Kings of Camouflage

Optics
Controlled appearance

The broadclub cuttlefish

Extended Papillae
Retracted Papillae

Roger Hanlon

Youtube: “The Octopus and the Beer Bottle"


Chromatophores
Iridophores
Leucophores

Length scales relevant for functionality in nature

Multifunctional materials require hierarchical morphologies with 3D structure control from the nano- to the macro-scale

images courtesy of
http://www.quantum-immortal.net
Tom Kleindinst (WHOI), Roger Hanlon Shutterstock, Michel Villeneuve53 (Flickr)
education.mrsec.wisc.edu
Tomahawk Beat
PUPA Gilbert
Ling Li
NIH
complexity in morphology

natural material systems

emulate

man-made material systems

utilize

complexity in composition
Three overarching goals in the

1. Increasing the repertoire of materials for optical engineering: Which role can soft matter play in optical technology?

2. Pushing the limits of functionality directly at the materials level. Organisms in nature incorporate multiple functions on the materials level. Can we copy that efficiently?

3. Explore new paradigms in the fabrication of optical materials. Can we grow functional materials, with better control of structure across multiple length scales?
Biomimickry (a.k.a. Biomimetics) vs. Bioinspiration
Talk outline

Reconfigurable fluid compound micro-lenses


Using fluids to create bio-inspired, tunable, optical components

Pressure indication in compression bandages with photonic fibers


Using elastomers to create bio-inspired, tunable, optical components
Inspiration - vision of nocturnal mammals

Moritz Kreysing
MPI, Dresden

Jochen Guck
BioTec, Dresden

Emulsion morphologies can be controllably adjusted using surfactants.

The emulsion drops can act as lenses.
Modeling of emulsion droplet properties

100µm

Incident light

Vishnu Shresht
Sara Nagelberg
Visualization of lens-light interaction

Nagelberg et al., in preparation
Quantifying variation of focal length

Sara Nagelberg

Input Image

Droplets

Output Image

100µm
Quantifying the lenses’ dynamic optical properties

![Graphs and images illustrating the lenses' dynamic optical properties with various parameters and metrics such as MTF, PSF, and NA.](image-url)
Potential for applications

Toward 3D displays & integral imaging

500µm
Potential for applications

Toward on-chip optical micro-tomography
Summary

- useful **inspiration for light manipulation can be gained from nature** (sometimes it’s right in front of our eyes - or like in this case in our eyes)

- fluids can be assembled to have morphologies that emulate the **key features of compound lenses** and other optical components

- easily achieved morphological changes in fluid compound lenses allow us to **tune the lenses’ optical properties using a variety of stimuli**

- **applications** for display technology, imaging devices, wavefront sensing and shaping, and light management in solar energy conversion
Biologically Inspired, Mechano-Sensitive, Color-Tunable Photonic Fibers

Collaborators:

Joseph Sandt
Marie Moudio
Chris Argenti
Marcus Urann
Andrew Milne
James Hardin
Pete Vukusic
Jennifer Lewis
A cheeky little fruit … “full of inspiration”

Mimetic fruits of the “Bastard hogberry” (*Margaritaria nobilis*)

Optical and electron microscopy images acquired by Alfie Lethbridge und Prof. Peter Vukusic, University of Exeter, UK
Bio-inspired mechano-responsive color-tunable photonic fibers

Key components in the fruit’s photonic structure:

Periodicity on the nanoscale:
=> color by constructive interference of light in selected wavelength ranges

Curvature on the microscale:
=> reflection of light into an increased angular range
The fiber morphology

- Core fiber
- Multilayer cladding

Scale markers: 20 µm and 1 µm
The reflection color of the fibers can be controlled by adjusting the film thicknesses in the initial double layer.
Reversible and controlled color-tuning in elastically deformable photonic fibers

Clustering of data points in CIE color space visualizes the homogeneity along fibers and the consistency in optical performance across fibers.
How can we tell the pressure inside the bandage?
Implications for the patient

- pain
- time
- cost
How could the fibers be useful for this problem?

“A bit of pressure is healthy.”

Wavelength vs. fiber strain

Pressure vs. bandage strain

Pressure [mmHg]

0.0 0.15 0.30 0.45 0.60

True Strain $\varepsilon$

0 10 20 30 40

strain $\varepsilon$

400 500 600 700 800 900 1000

$\lambda_{\text{peak}}$ [nm]
Colorimetric pressure sensors in compression bandages

Colorimetric pressure sensors in compression bandages

Pressure

Color

low

good

high

Pressure

low

good

high

Color

low

good

high

Color

low

good

high

Color
Fiber endurance

Cycle 1

$\varepsilon$

$F$ [mN]

$\lambda$ [nm]

True strain $\varepsilon$

Joseph
The team

Joseph Sandt

Chris Argenti

Matthew Carty, MD

Marie Moudio

The goal
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