Biophotonics

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Bio-Photonics

Biological matter

Photonics

Biological matter as optical materials

Photonics integrated into biological systems
Sensing, Imaging, Diagnosis

Biological samples, Human patients

Transmission
Phase
Spectroscopy

Photon

Elastic scattering
Polarization

Inelastic scattering
Fluorescence
Photoacoustic
Surgery / Therapy

Biological matter

Photon

Thermal
Mechanical
Chemical
Biological
Example: Laser Surgery

Holmium laser (2.4 µm, 100 W)
Example: Laser Surgery

Laser pulse
532 nm
10-1000 ms
Modern Light Radiation Therapy
Friedrich Meyer-Betz, a German physician, injected himself with porphyrin in 1912 to test whether it made humans sensitive to light. The first photograph shows him four days later, after he took a walk on a sunny day. Most of the swelling subsided by the sixth day, second photograph, but he remained light-sensitive for several months.
Opthalmic OCT
Refractive correction
Hair removal
Photoablation of BPH

Oximetry
Optical tomography

Endoscopy
Intraoperative imaging
Optical diagnostics

Dermatologic treatments
Dental
Laser surgery
Light-activated therapy

UV therapy
Blue light therapy
Photodynamic therapy
NIR therapy
Light-activated nanomedicine

Intravascular imaging
Implants
Wearables
Oximetry

Colonoscopy

Light in Medicine
Yun & Kwok,
Implantable Photonic Devices
(Research)
Flexible Light Emitting Diodes (LED)

Gao et al., Nat Comm. 2014

Kim et al., Nat Materials 2010
Optogenetics Implant

Light induced activation or silencing of neurons and nerves

Kim et al., Science 2013

Canales et al., Nat Biotechnology 2015
Wireless or muscle-powered LED

Folcher et al., Nat Comm. 2014

Ho et al., PNAS 2014

Lee et al., Bio Energy 2015
Cell-based Sensing & Therapy
Light-Guiding Hydrogel

Twisted

PEG-DA, 5 kDa, 10% wt

Baseline

Light coupled

Light profile

Choi et al., Nature Photonics (2013)
In Vivo Implant

Choi et al., Nature Photonics (2013)
Optogenetic Cell Therapy


Choi et al., Nature Photonics (2013)
Hydrogel Optical Fibers

PEG (80%) Core
Alginate (2%) Clad

Choi et al., Adv. Materials 2015
Highly stretchable hydrogel fiber

Relaxed  

Stretched  

10 cm

Polyacrylamide (40%) / Alginate Core  
Polyacrylamide (20%) / Alginate Clad

Sensing region

Light

Absorber  
Scatterer

ε=100%

Guo et al., Adv. Materials 2016 (in print)
Optical Strain Sensing

Guo et al., Adv. Materials 2016 (in print)
Biodegradable Polymers

Nizamoglu et al., Nat. Comm. 2015
Photochemical Tissue Bonding

(i) Apply dye
(ii) Insert waveguide & Illuminate light
(iii) Bonding formed & Cut out waveguide

Nizamoglu et al., Nat. Comm. 2015
Bio-Lasers
Fluorescent Proteins

Lasing from GFP-expressing cell

Solid-state GFP ring-cavity


Intracellular Microsphere Laser

Humar & Yun, Nat. Photonics (2015)
Microcavity Sensing: Extended

Vahala, Nature 2004
Vollmer & Arnold, Nat. Methods 2008

Fan & Yun, Nat. Methods (2014)
Response to osmotic pressure

\[ \frac{n_0 - n_w}{n - n_w} = \frac{c_0}{c} = \frac{V}{V_0} \]


- 10 g/L NaCl
- 8 g/L NaCl
- 0.36 nm
- 10 pm (\(\Delta n = 3 \times 10^{-4}\))

Oil droplets

Polyphenyl ether (PPE, n=1.61) + Nile red

Intracellular force sensing

\[ \Delta \sigma = 2\gamma (H_1 - H_2) \approx 4\gamma \frac{a - b}{a^2} \]

\[ \gamma \approx 45 \text{ mN/m} \]

\[ \frac{a-b}{a} = 10\%, \ \Delta \sigma = \sim 500 \text{ Pa} \]

Intracellular fluctuation

\[ \langle \Delta \sigma \rangle = 150 \text{ pN/\(\mu\text{m}^2\)} = 150 \text{ Pa} \]

\(\Delta \text{Force} \approx 10 \text{ nN}\)

Lipid droplet

Adipocytes: Lipid (n=1.47), Nile red dye

Lasing in tissue

Barcoding

Polystyrene bead
Spontaneous emission

Intensity (a.u.)

Wavelength (nm)

Pixel count

Diameter (nm)

Diameter (µm)

8 to 12 µm / 2 nm = 2,000 identifiers
Injectable Lasers

**Current paradigm**

- Laser

Biosystem (cell, tissue, organ)

**New paradigm**

- Bio-lasers at micro / nano scale

- Bio-system
Imaging Laser Particles

Excitation beam

LASE (laser-particle)

Bright-field imaging

Two-photon imaging

Signal intensity

\[ S \sim I \]

\[ S \sim I^2 \]

\[ \text{Signal}= \int S \, dx \, dy \]

LASE Microscopy

LASE: laser particle stimulated emission

Perovskite nanowire

Summary: Biophotonics

- Light is a useful tool in biology and medicine
- Rich interactions between photon and matter
- Integration of photonics and biological systems

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