

Optoelectronic Technologies for Leadless Modulation of Cells with Sub-Cellular Resolution

Menahem (Hemi) Rotenberg, PhD

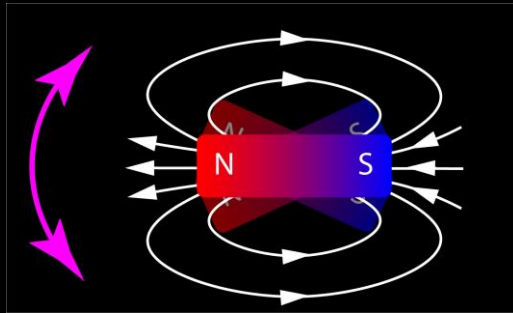
BME department, Technion, Israel Institute of Technology

CRS 2025, July 2025 Philadelphia, PA, USA

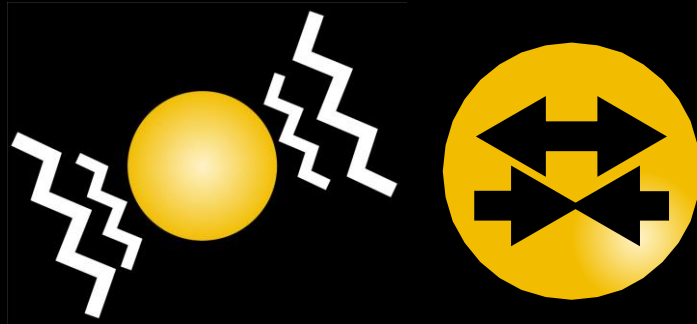
Bioelectric and Biomechanical interfaces

Magneto mechanical

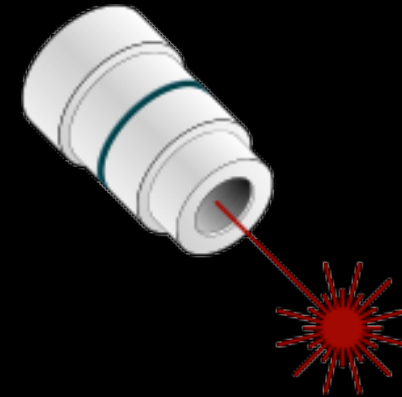
Stretch/compress



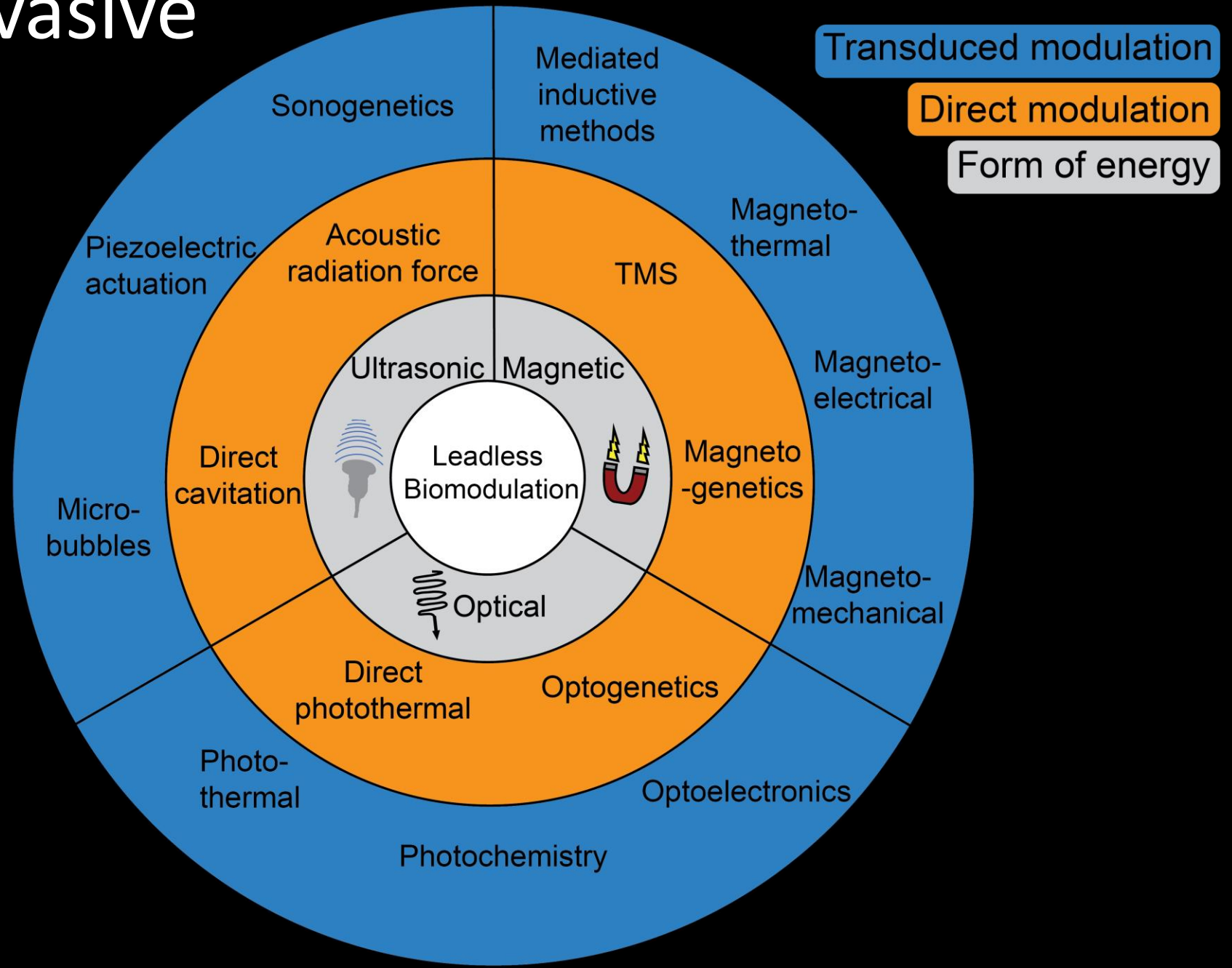
Alignment



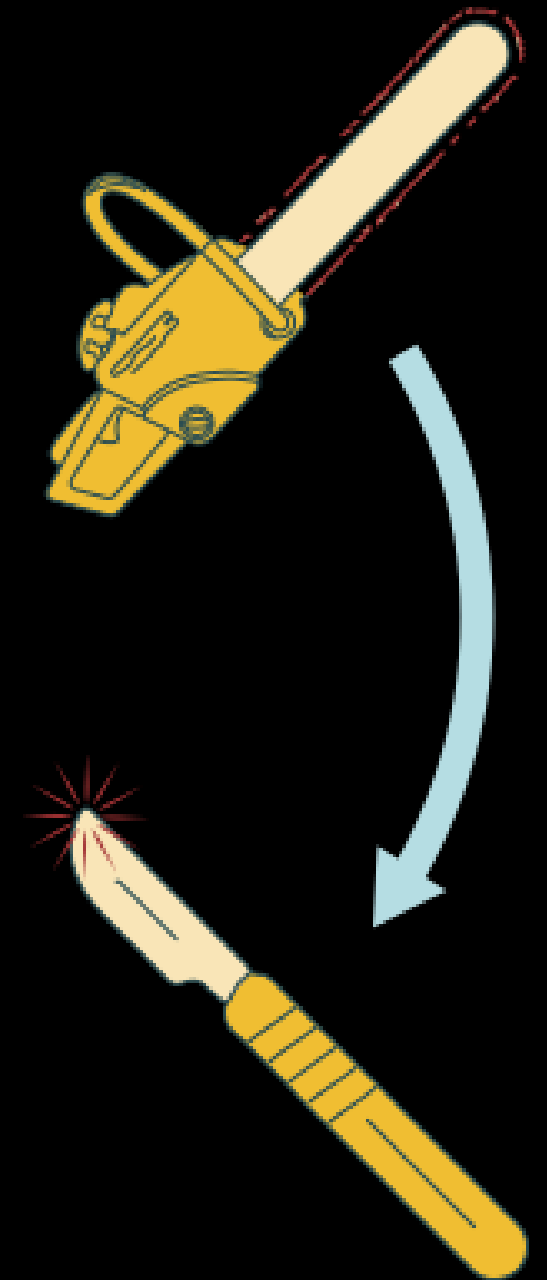
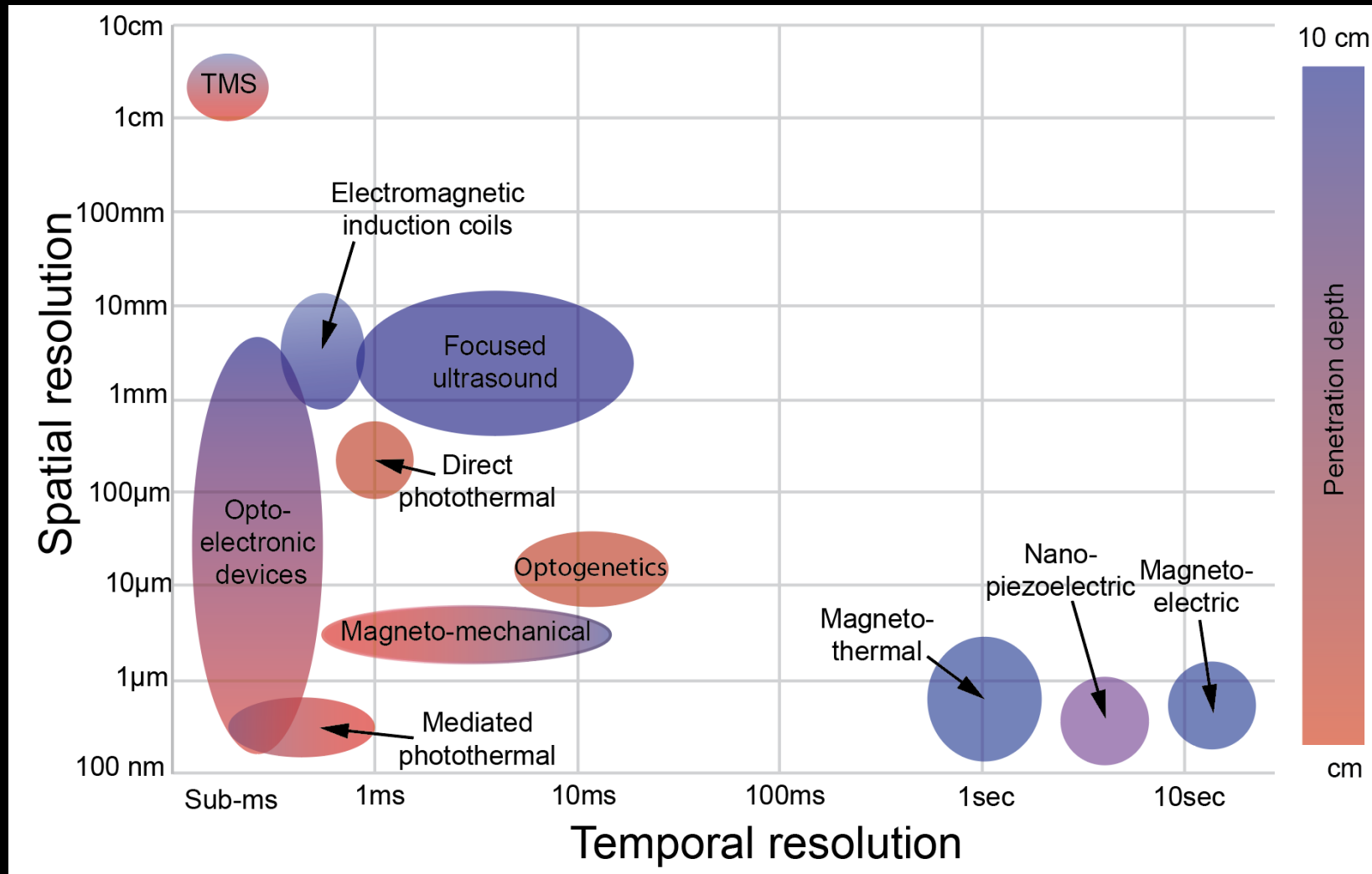
Optoelectronic



Minimally invasive Modulation:

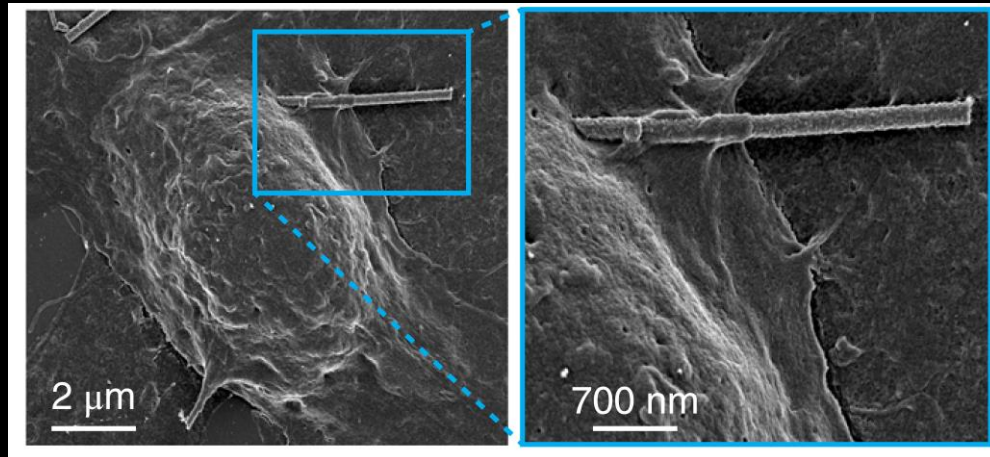
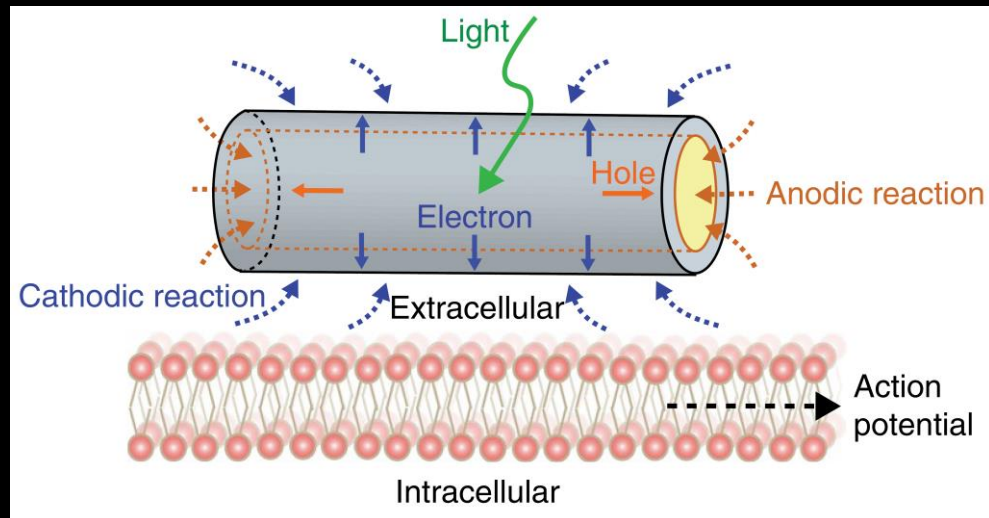


Modulation:



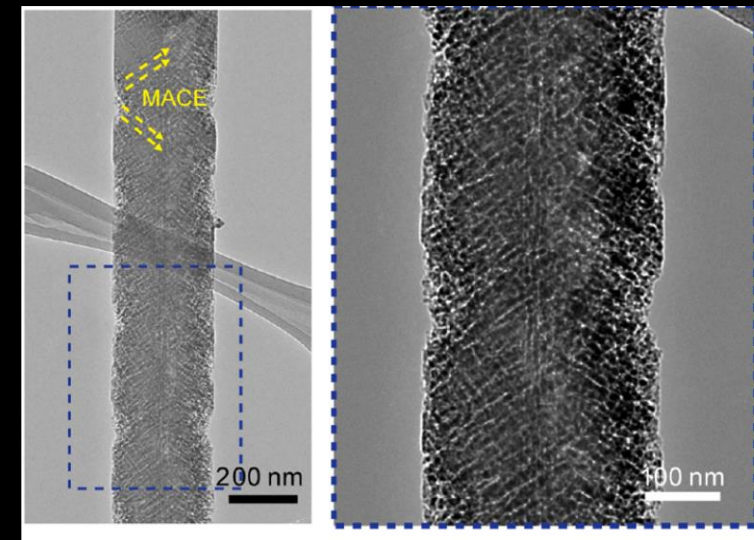
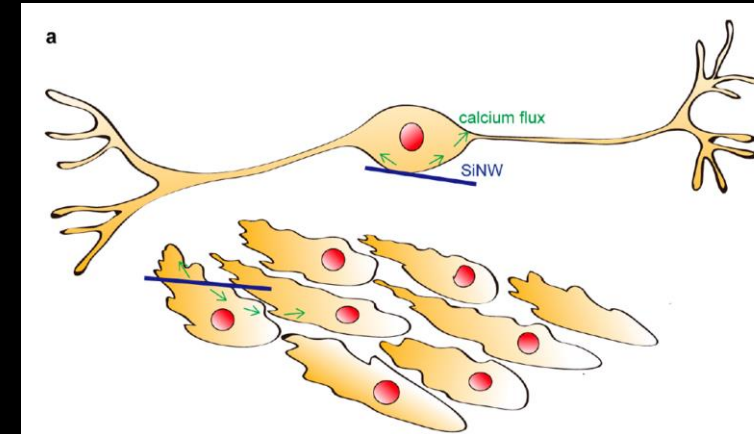
Silicon nanowires used as photo-stimulators:

Photo-electric



Parameswaran et al. Nature nanotechnology (2018)

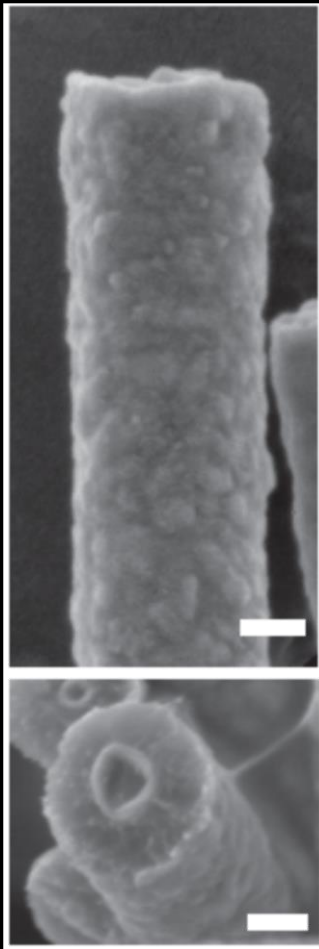
Photo-thermal



Fang et al. Nano letters (2018)

Intracellular optoelectronic modulation

SiNW

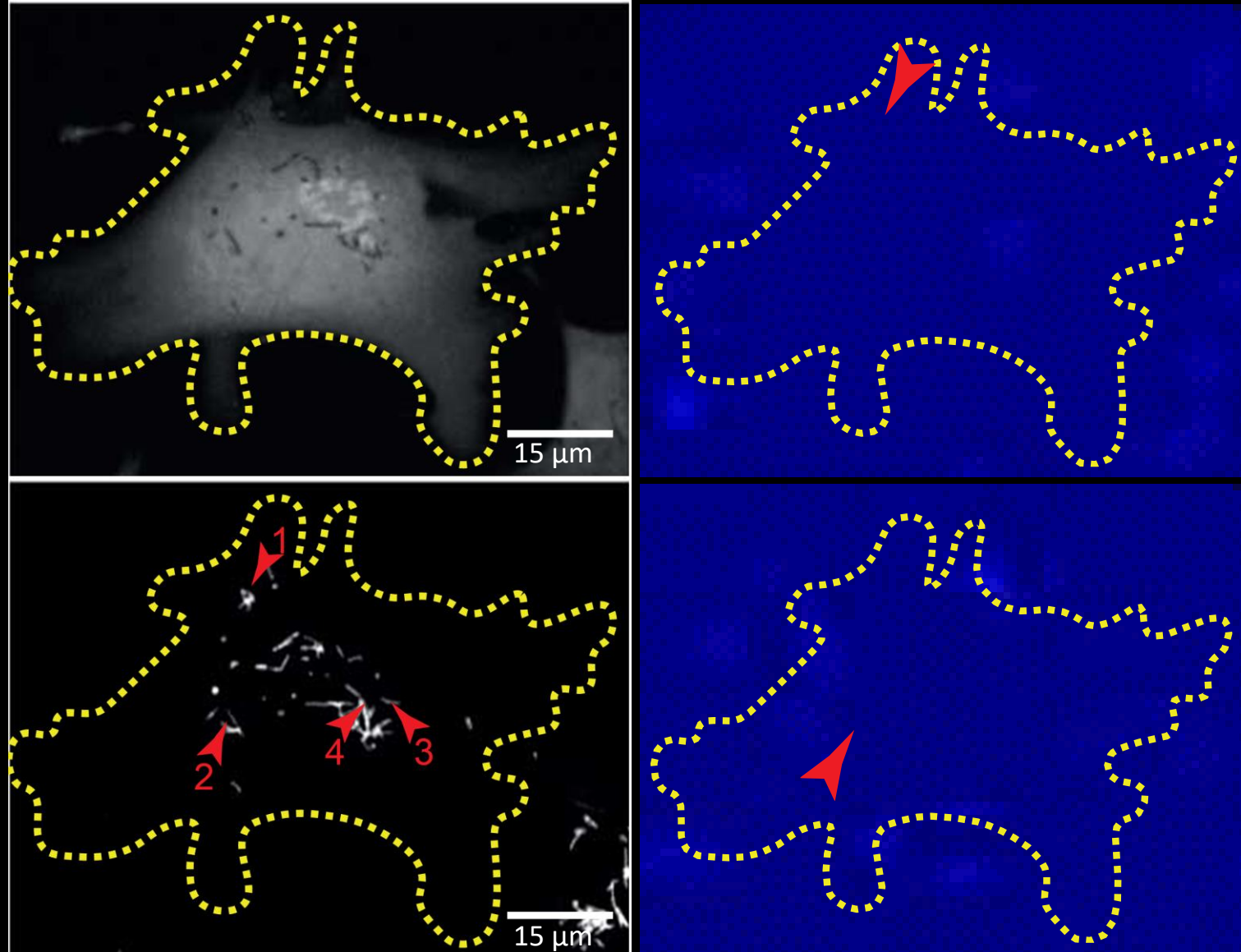


Cell-Si hybrid dividing



Intracellular optoelectronic modulation

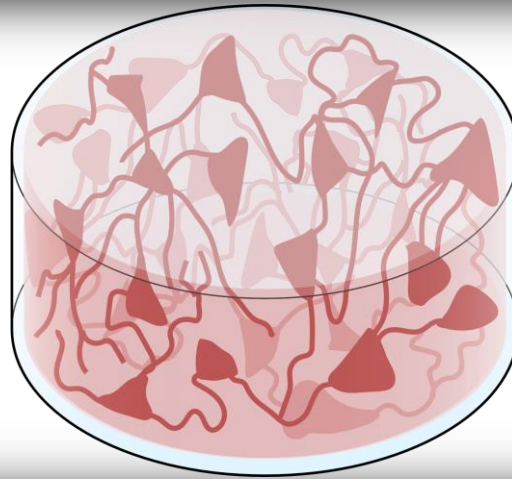
Cardiac
Myofibroblasts



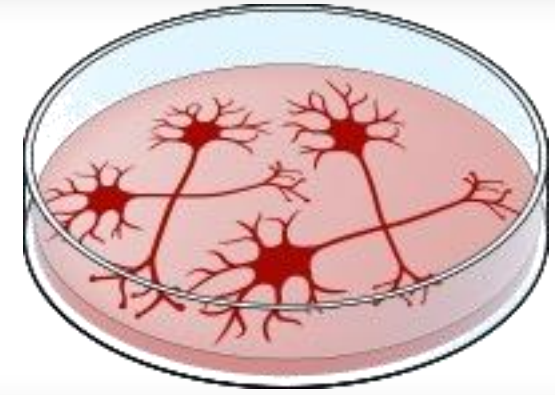
Subcellular stimulation within 3D tissues

State of the art:

3D culture



2D culture



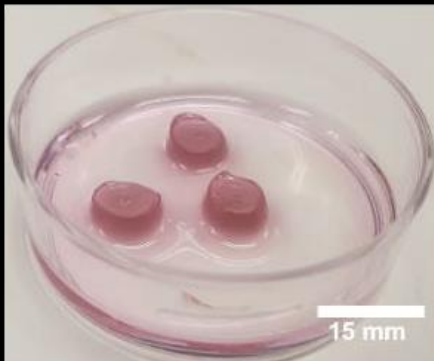
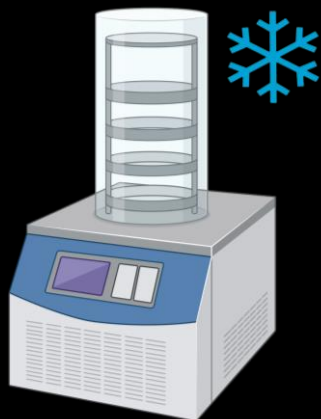
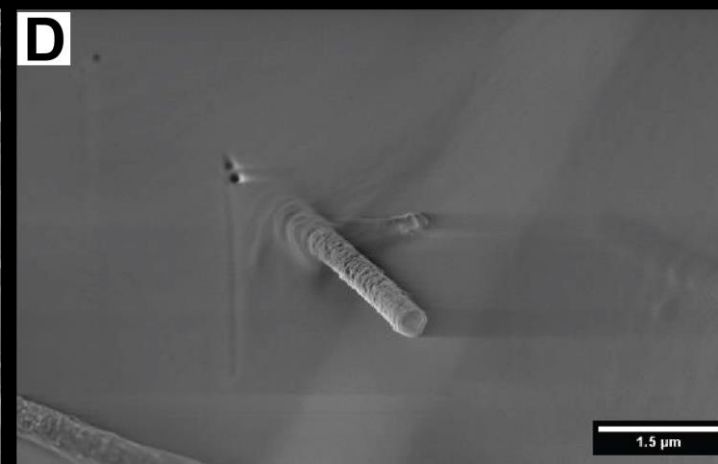
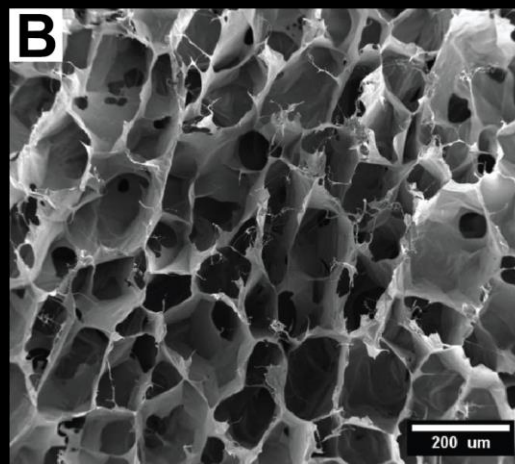
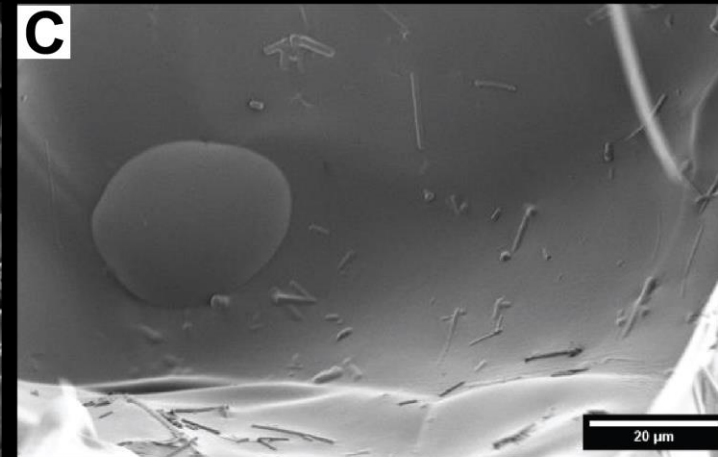
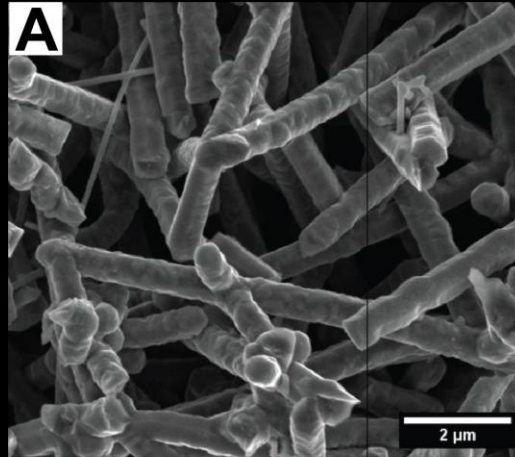
Sub-cellular resolution



Intra-volumetric access



E-Scaffold fabrication

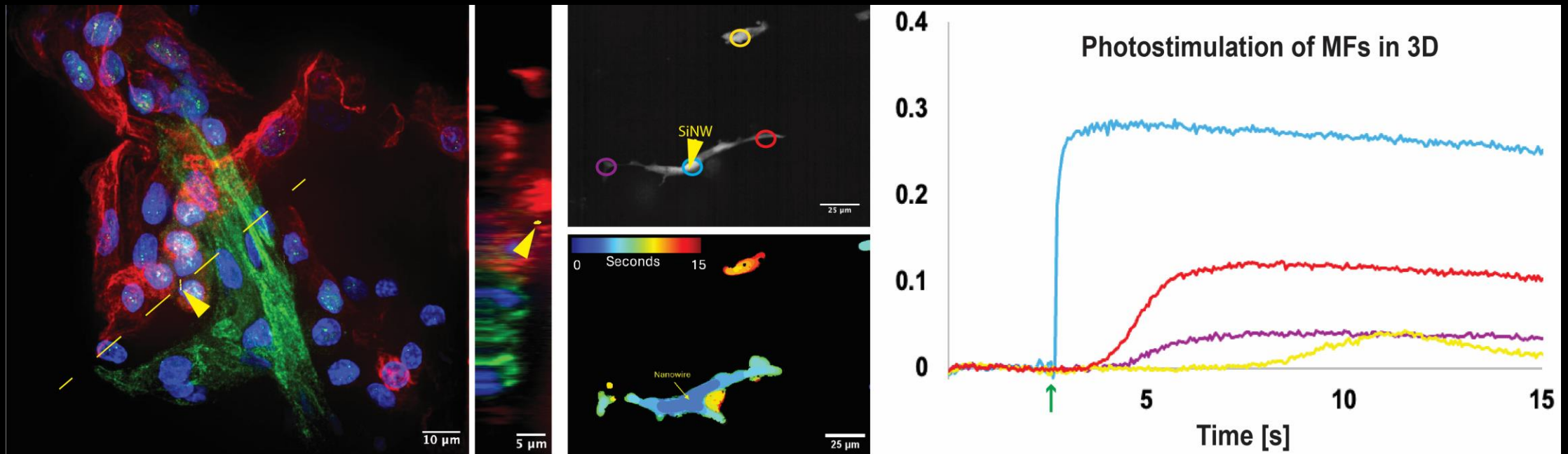


Nadi Hathot

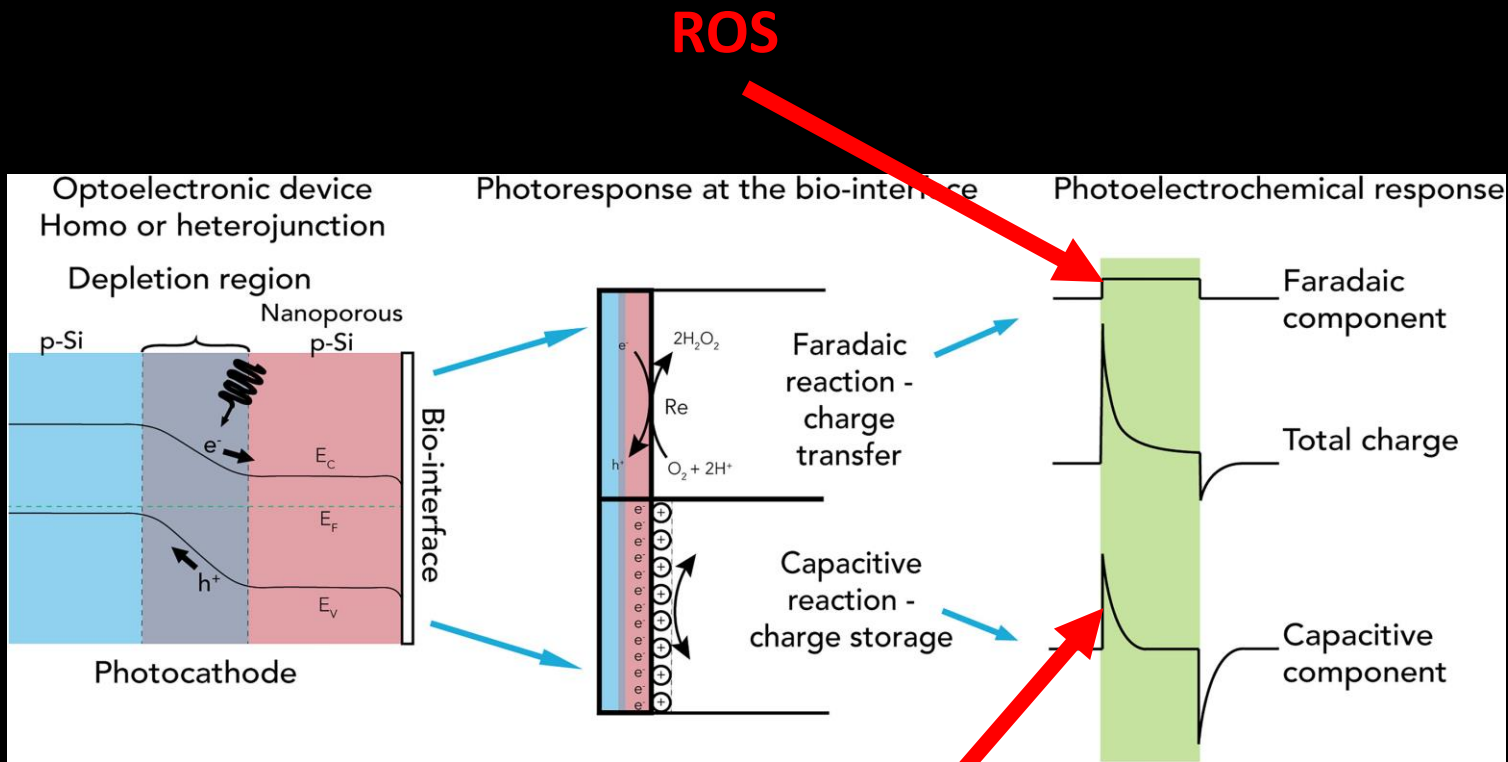


Tania Assaf

Leadless Intracellular optical modulation in 3D



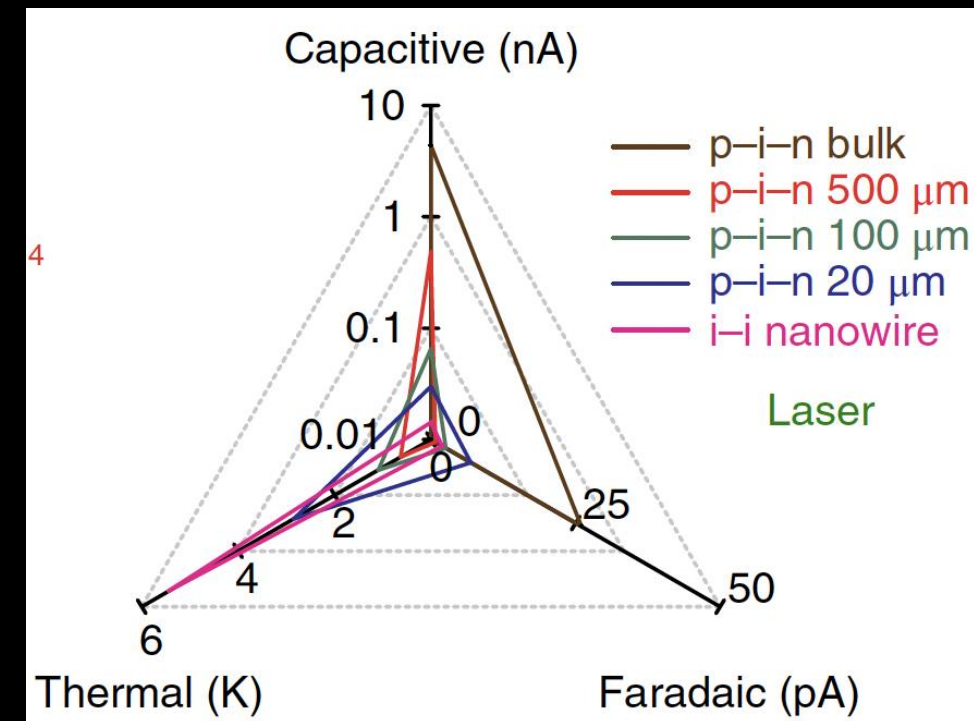
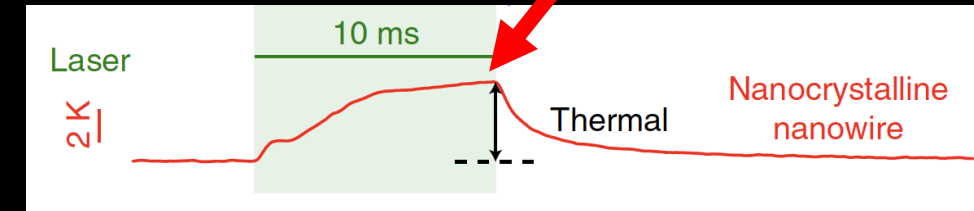
What is the underlying mechanism?



Yitzhak-David and Rotenberg. Cell Reports Physical Science (2023)

Photovoltage

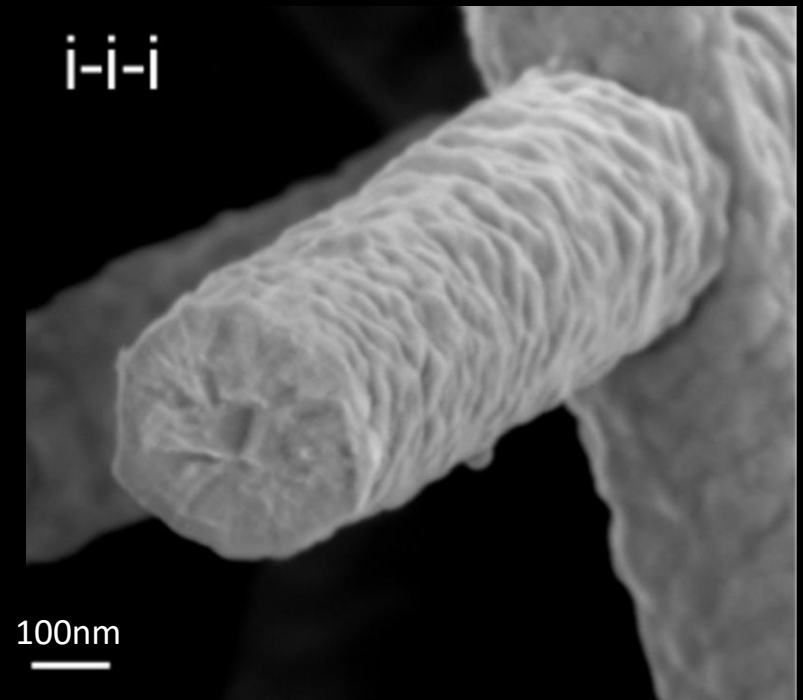
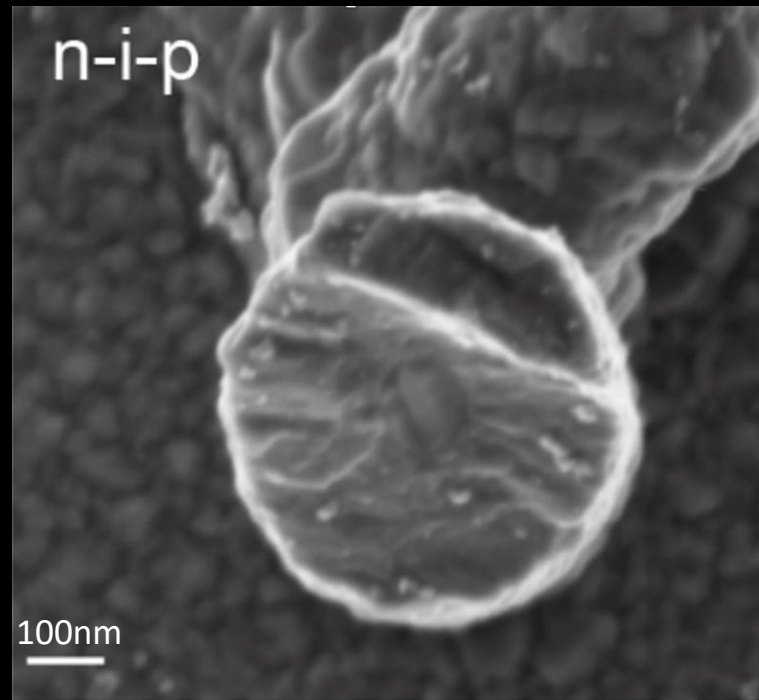
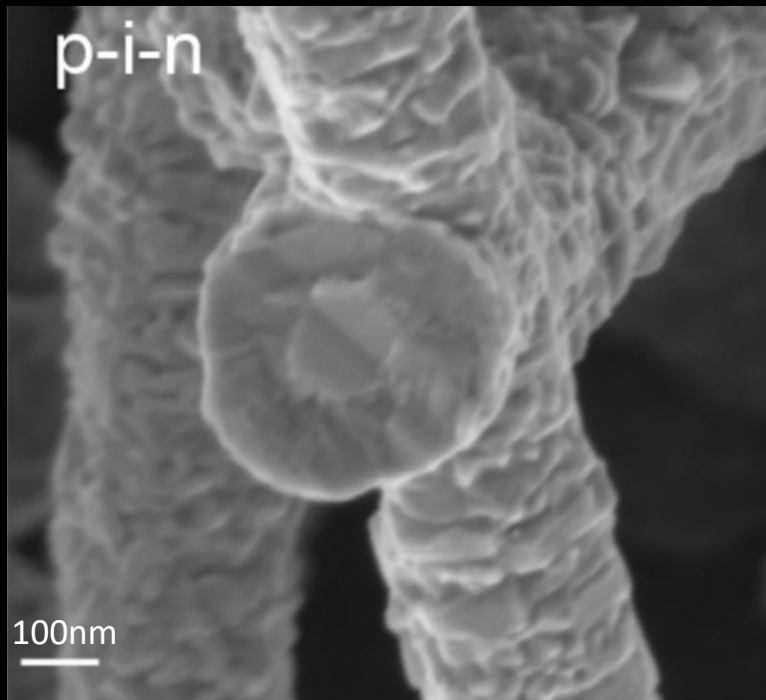
Photothermal



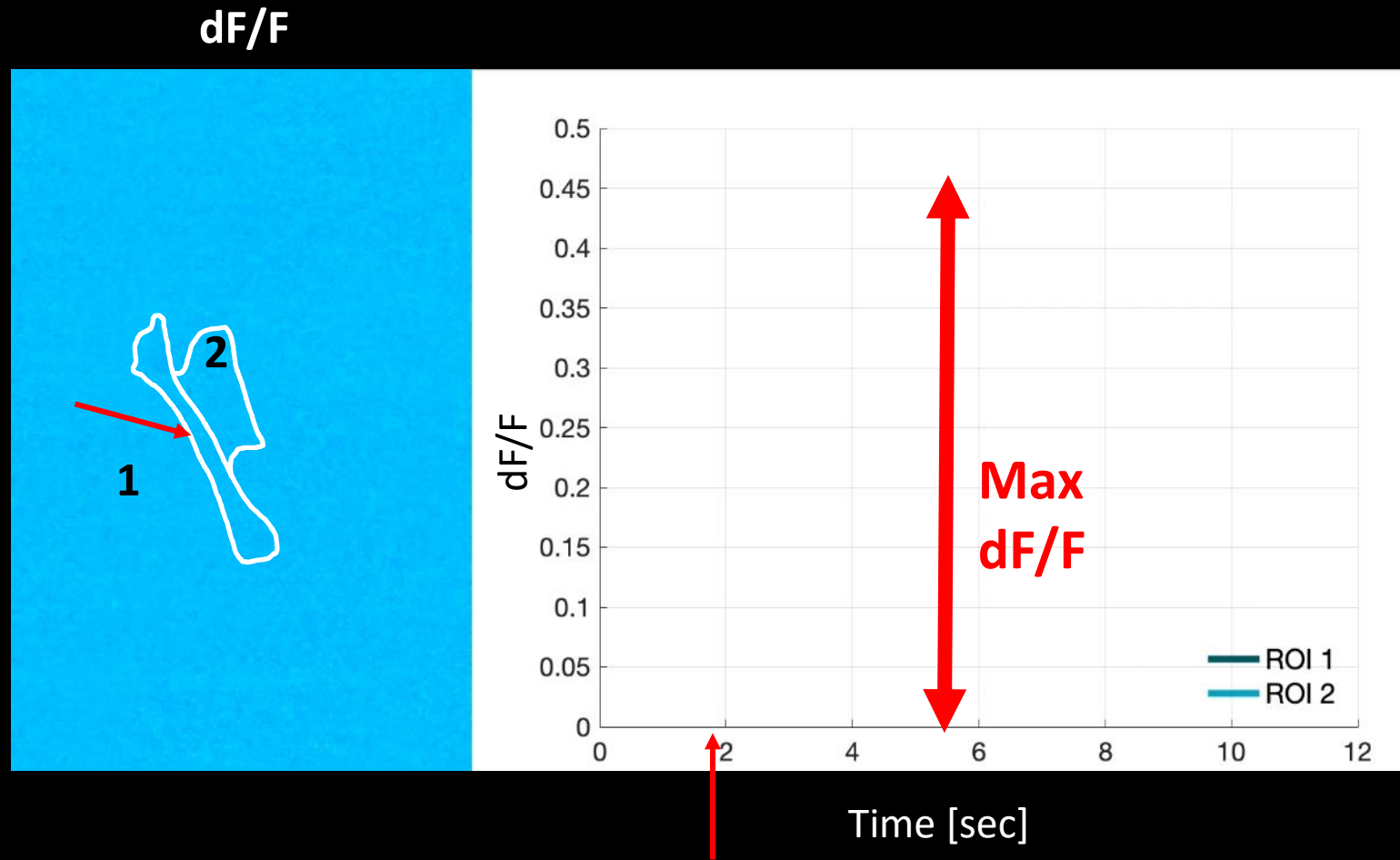
Jiang et al. Nat Biomed Eng (2018)

What's the underlying mechanism?

	Photoelectrochemical Effect	Photothermal Effect
p-i-n	+ (Dominant cathodic effect)	+
n-i-p	+ (Dominant anodic effect)	+
i-i-i	-	+



Calcium response to Optical Stimulation



Laser pulse: 640 nm, 2.75 mW

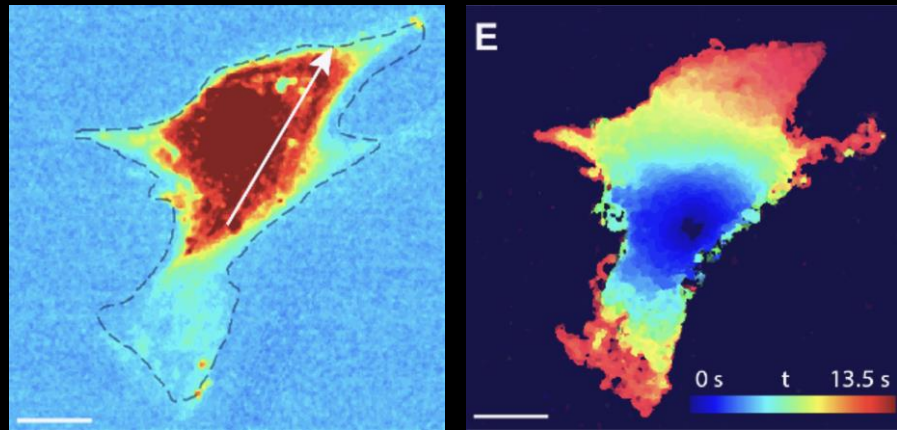
Tania Assaf



Intracellular Calcium Velocity

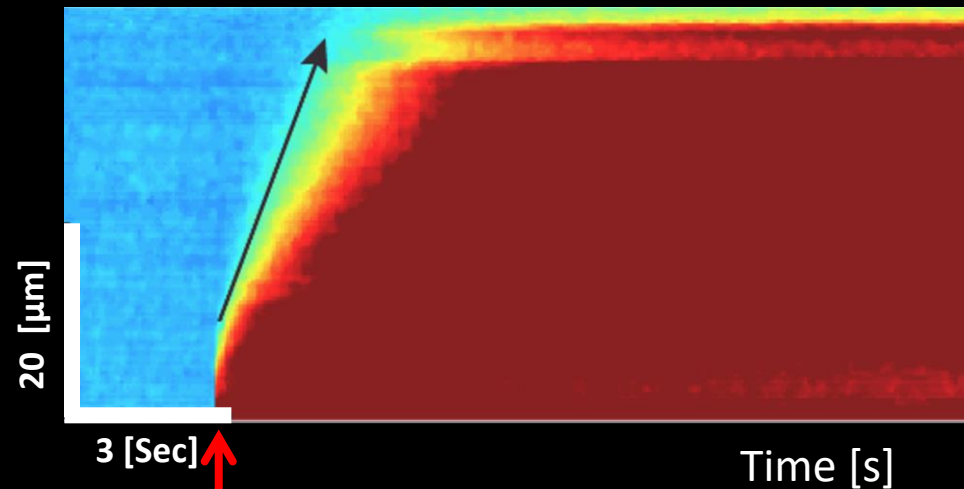
dF/F profile over time

Kymograph methods



Reslice

X [μm]

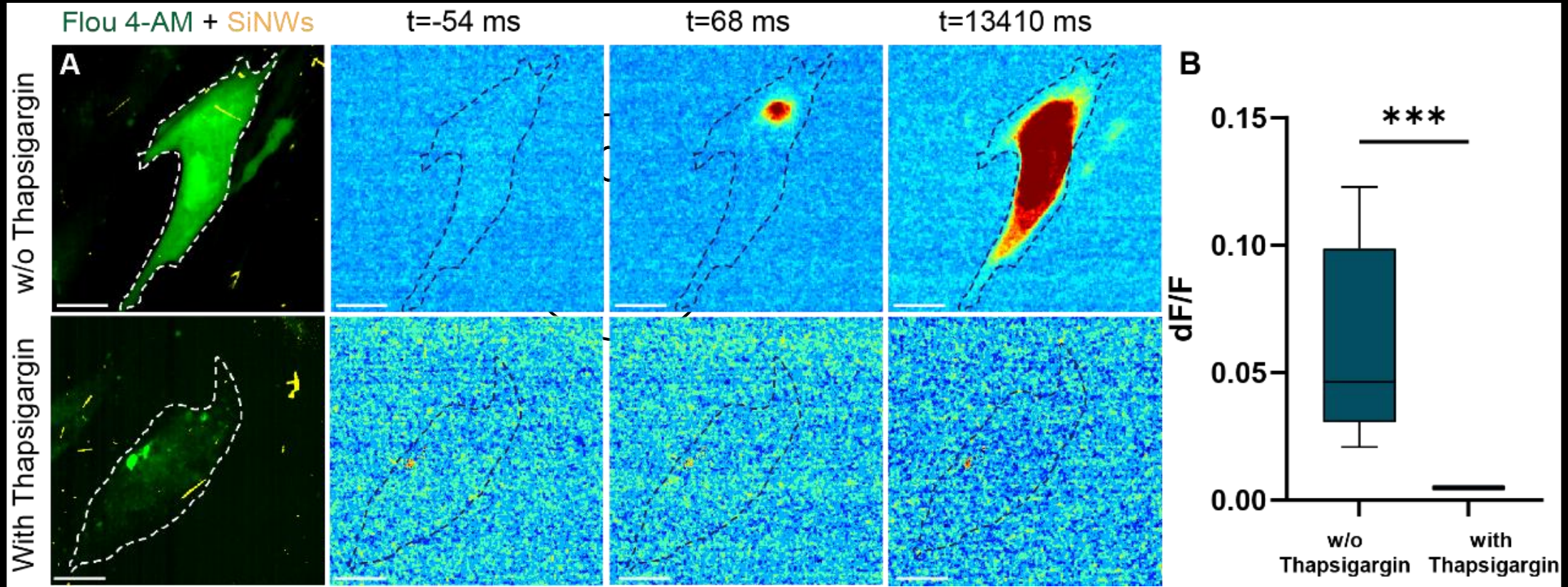


Stimulation

$$V = \frac{dx}{dt}$$

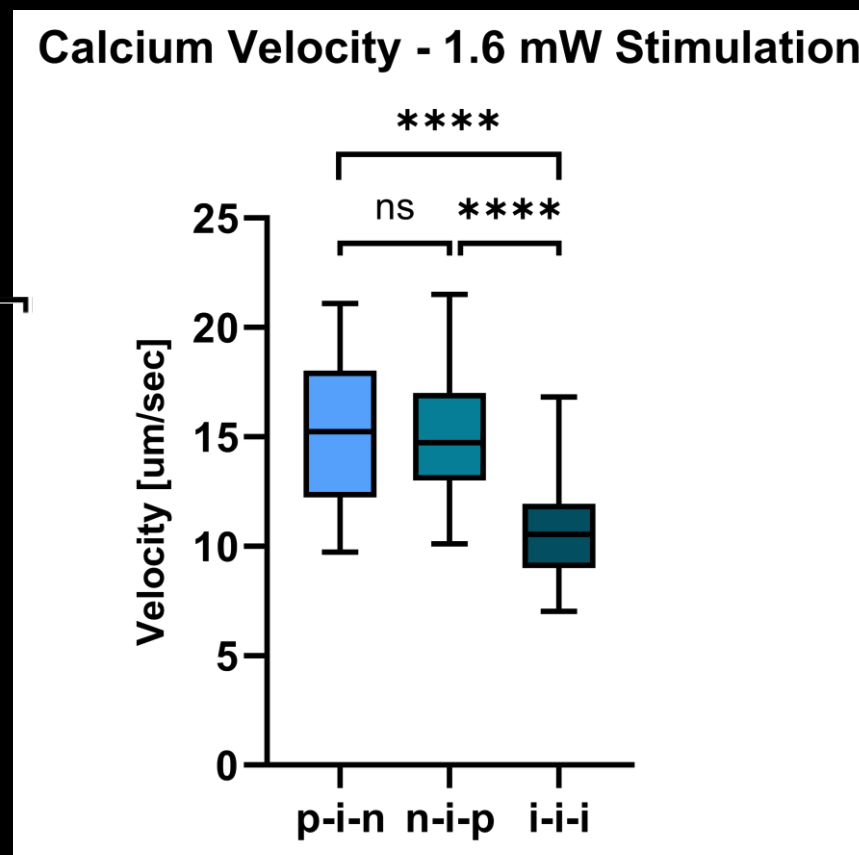
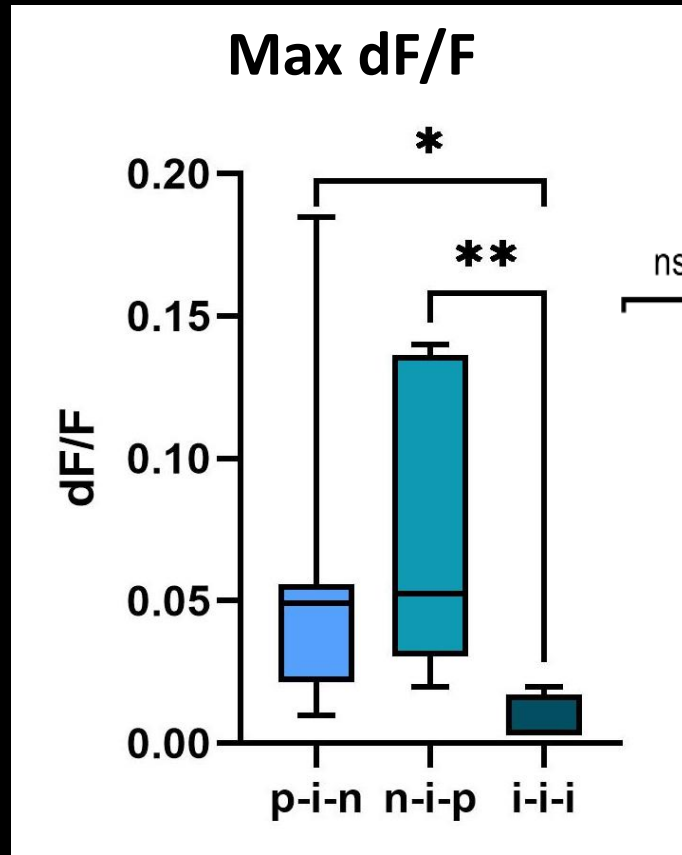
Calcium propagation velocity

Calcium source is internal

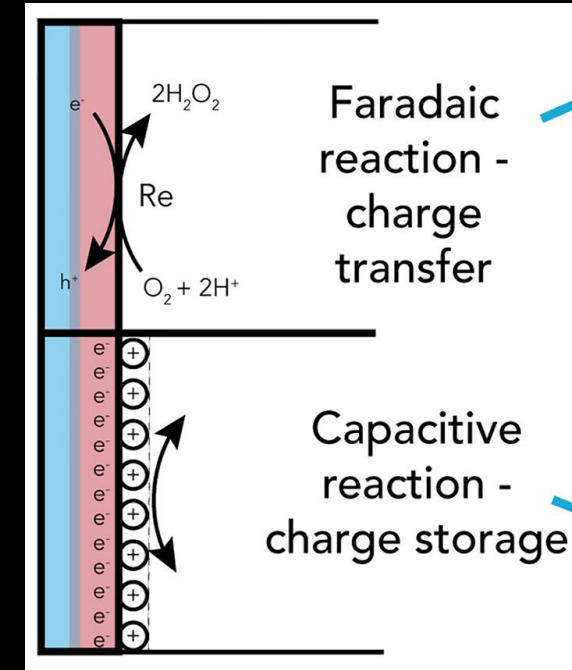


Scale bars=20 μm , Fluo-4 AM- Calcium dye

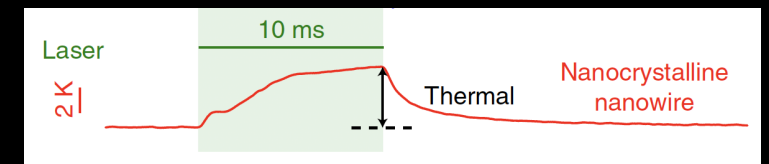
Calcium response:



ROS or Photovoltage



Photothermal

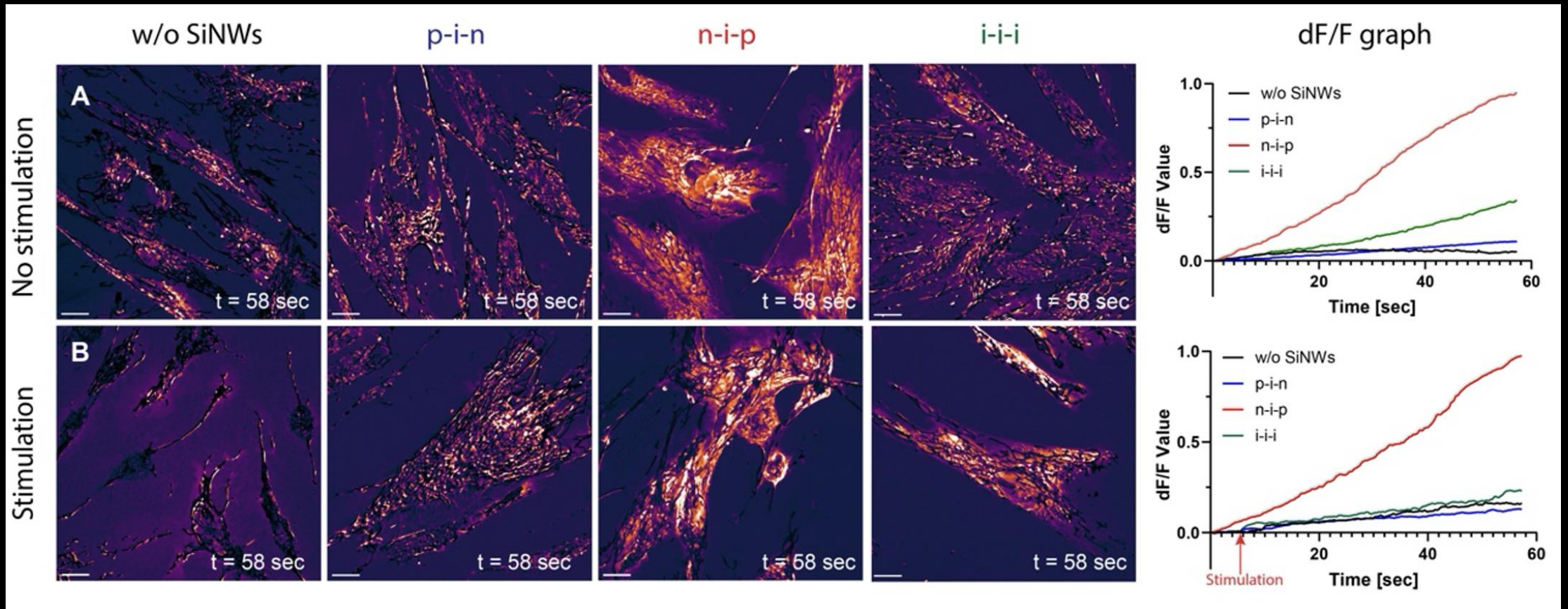


*- $p - value < 0.05$

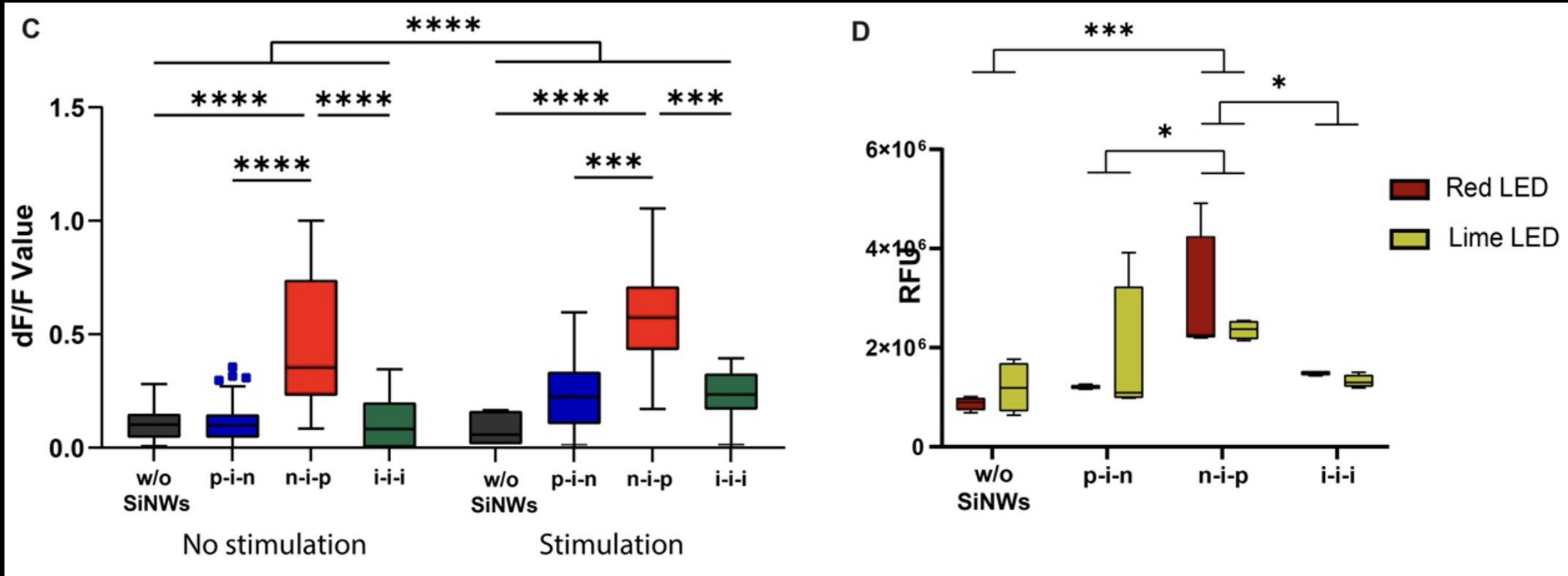
** - $p - value < 0.005$

**** - $p - value < 0.00001$

Photoelectrochemical Formation of ROS

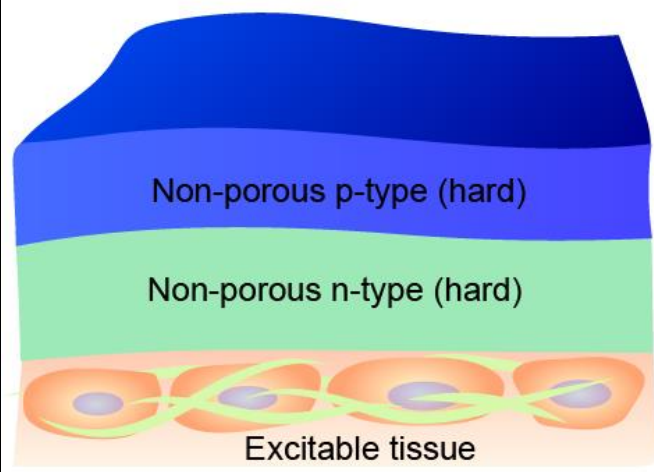
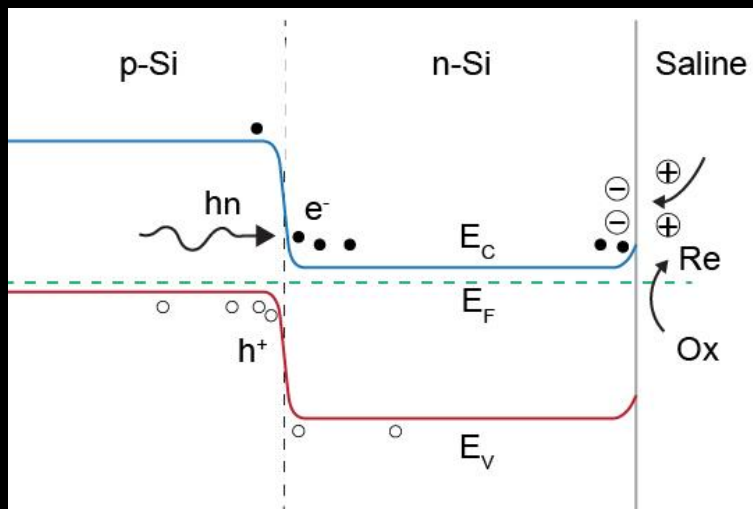


Photoelectrochemical Formation of ROS

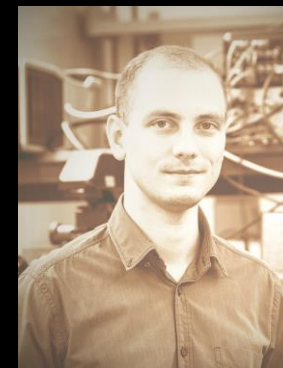
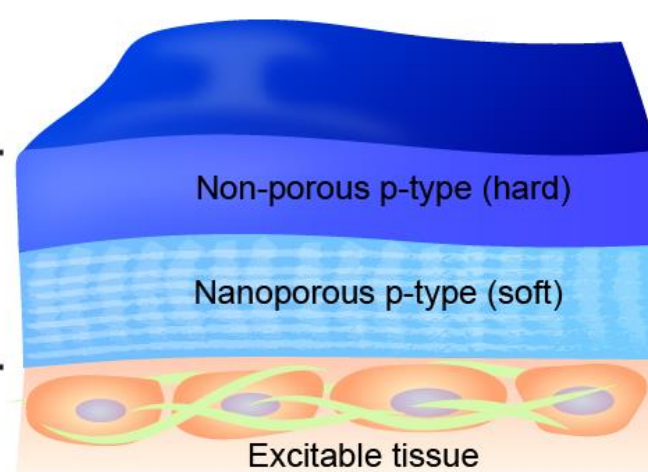
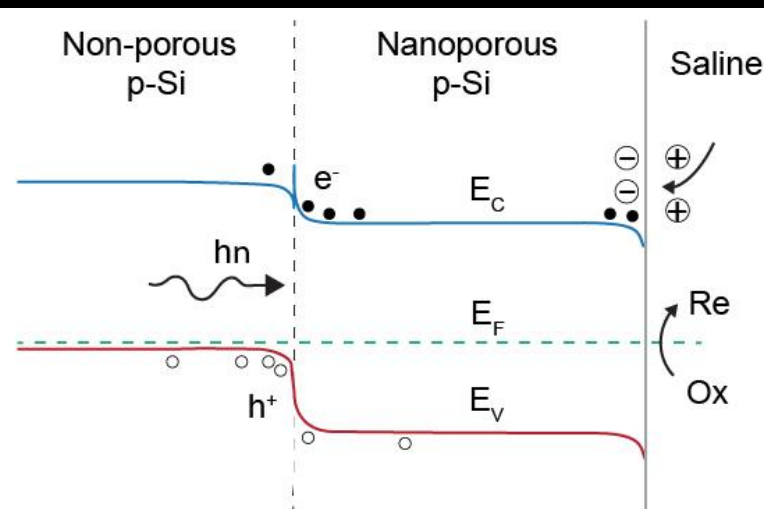


Opto-electronic devices

Traditional p-n junction



Porosity-based junction

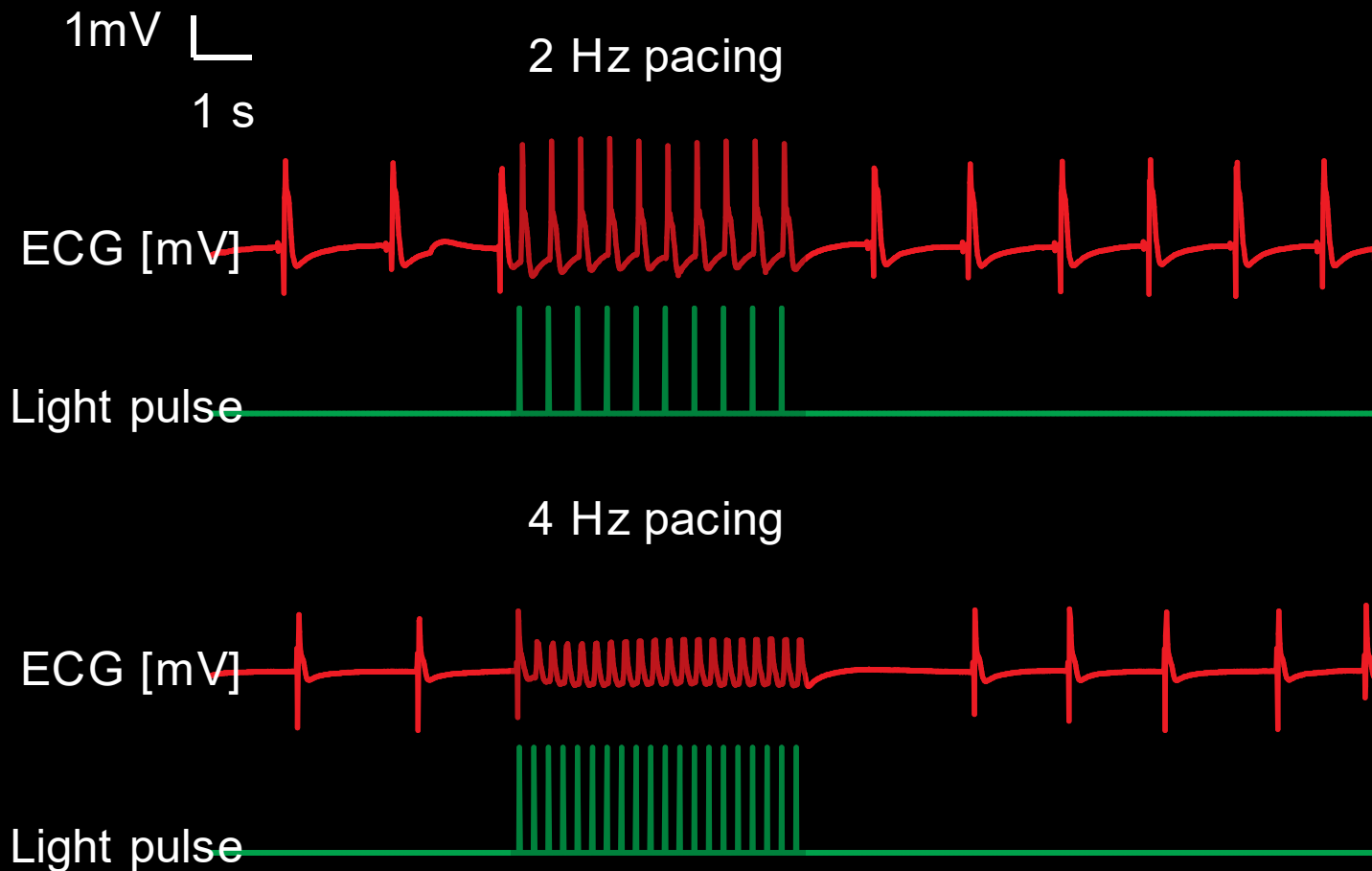


Aleksander Prominski, PhD



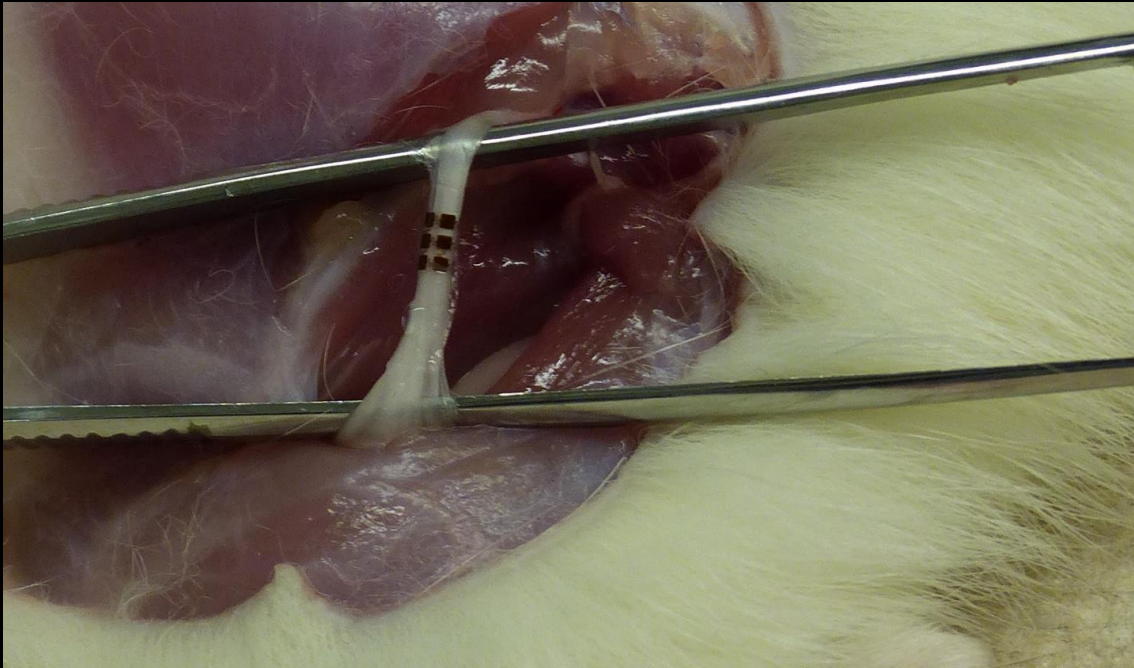
Prof. Bozhi Tian

Optical Heart Pacing



Exposed Sciatic nerve

Optical modulation



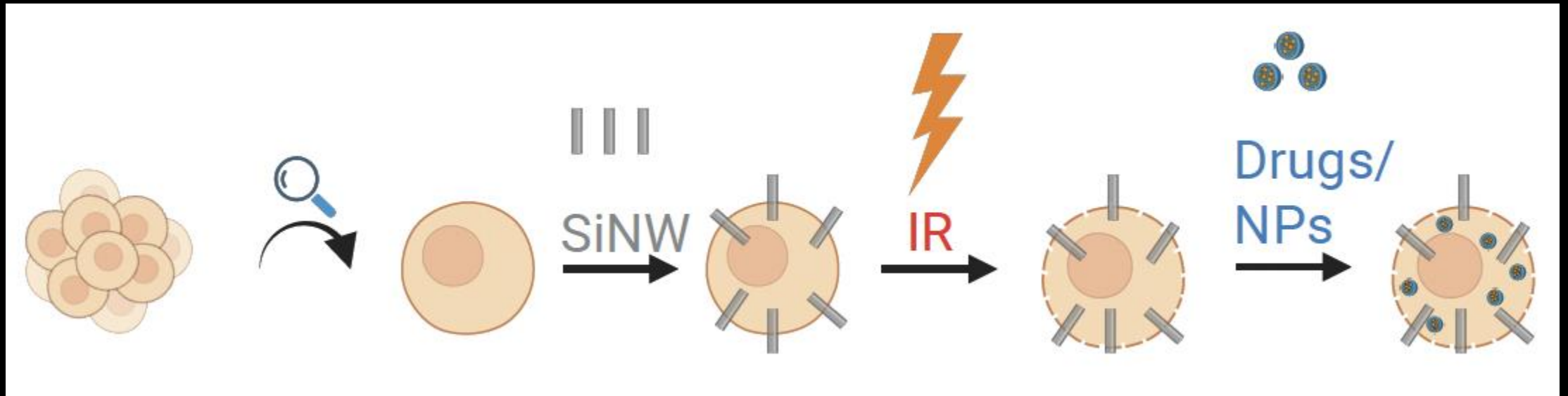
Can we use nanostructures to optically enhance penetration?



Dana Nir

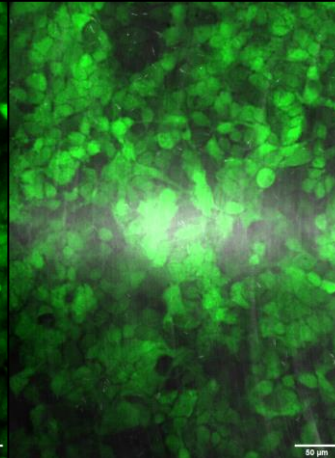
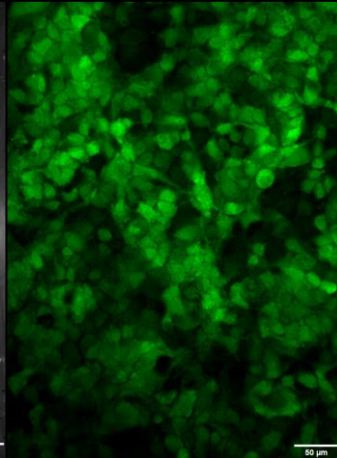
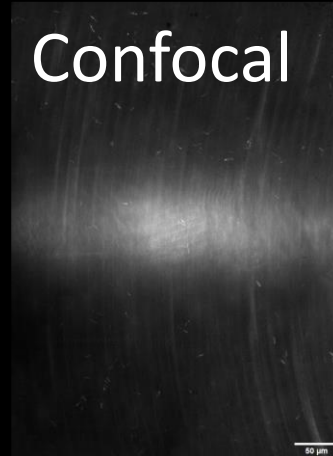
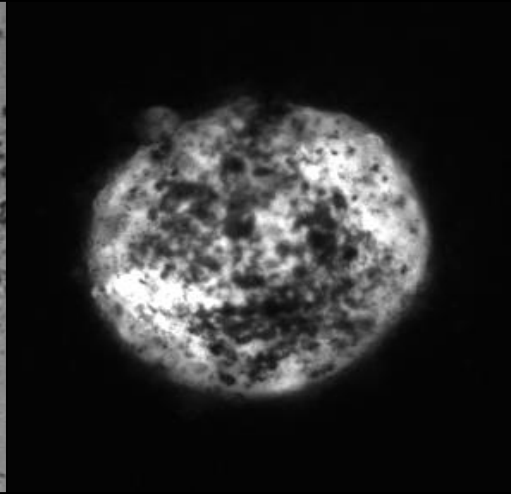
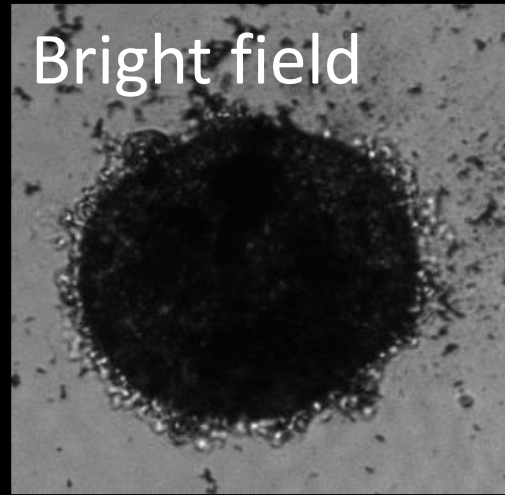


Prof. Yosi Shamay

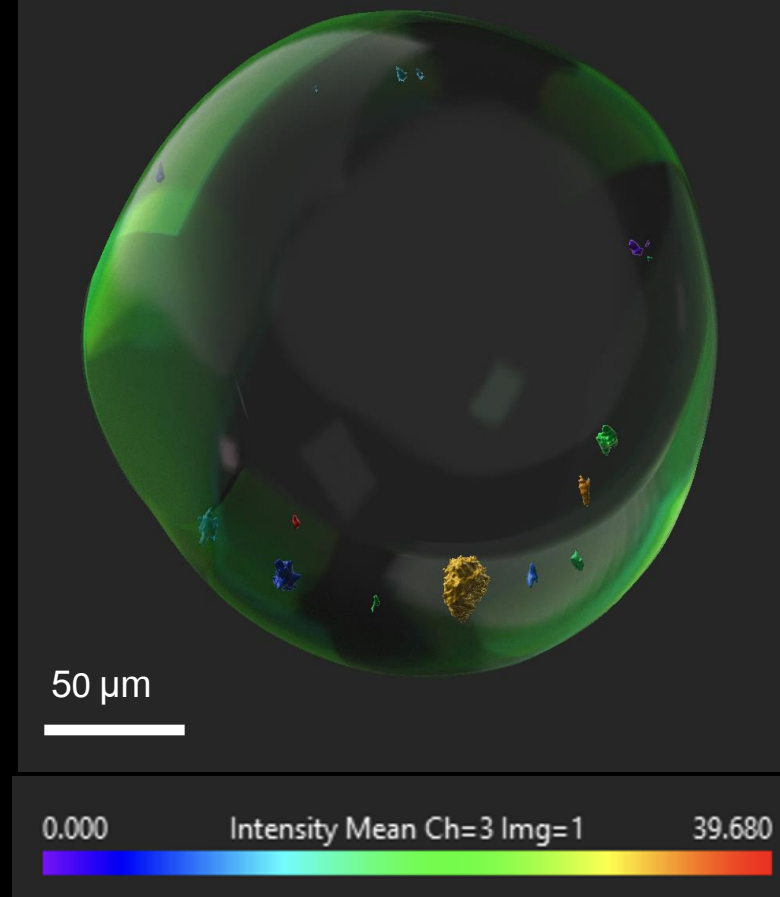


Cell Model- Cal33 cells, Head and neck squamous cell carcinoma

Silican nanostructure penetration into organoid

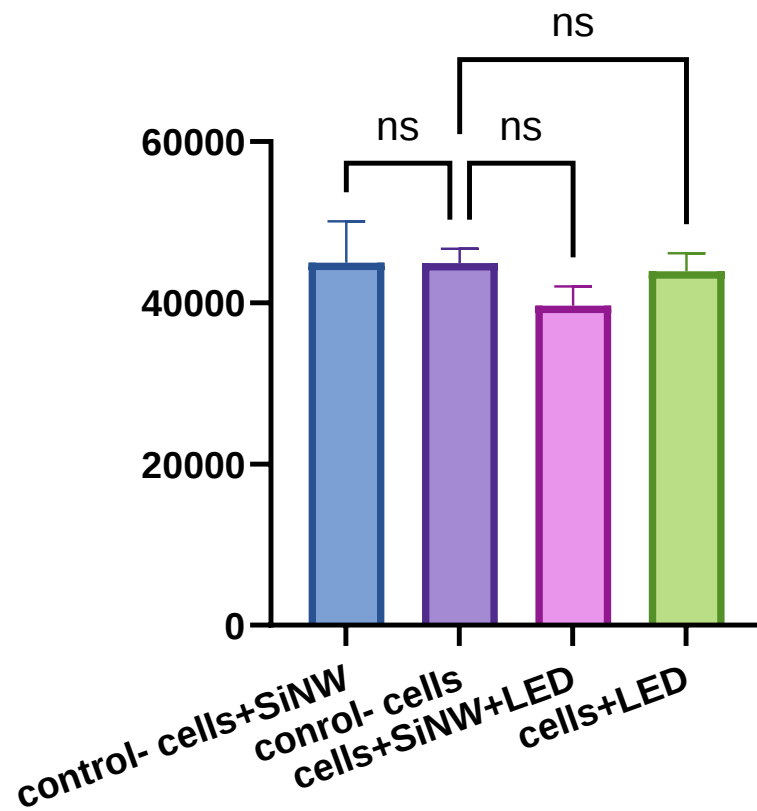


Light sheet microscopy

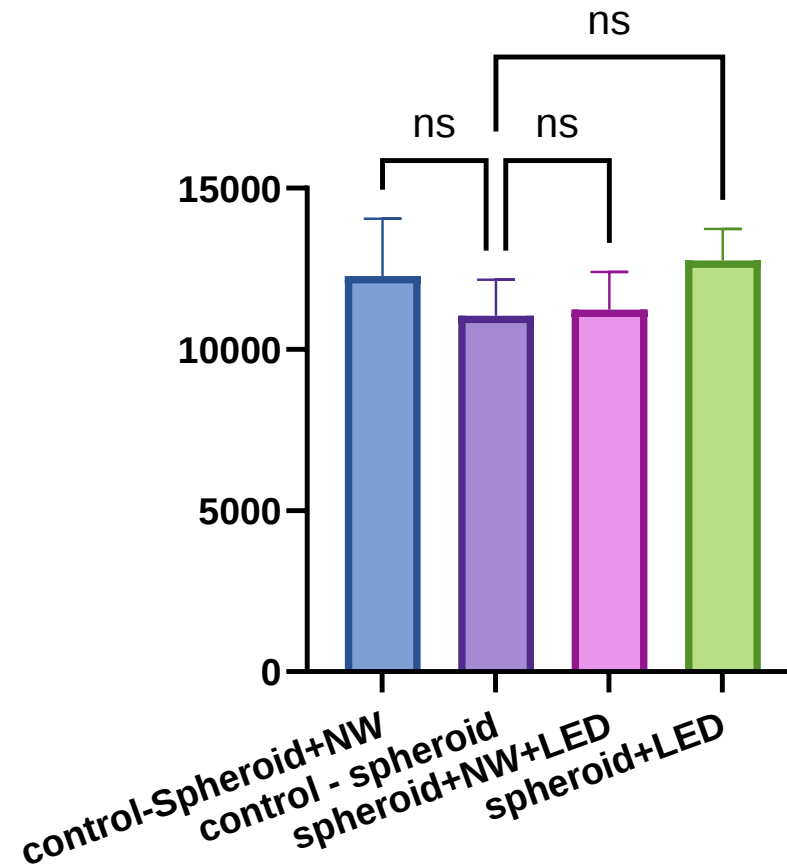


Cal33 Cells are not affected by Si nanostructures

2D viability after 72h from excitation

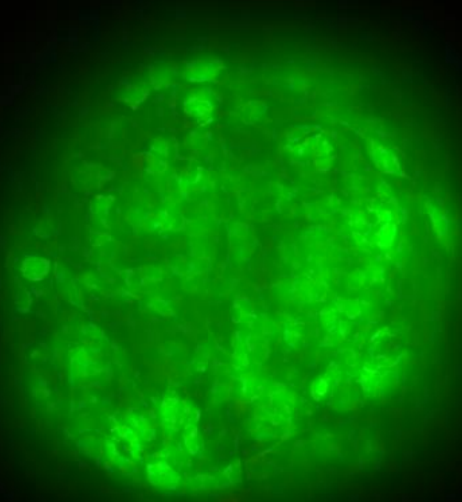


3D viability after 96h from excitation



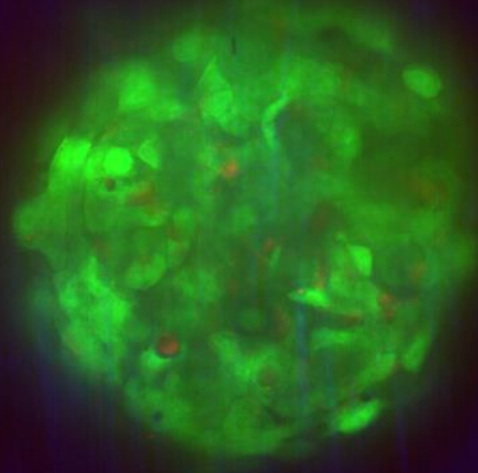
PI penetration into organoid

PI



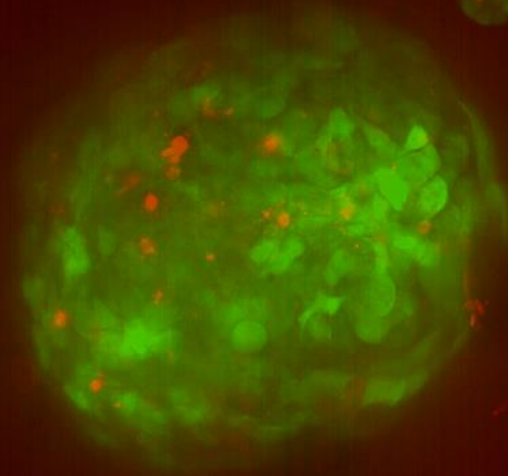
50 μ m

PI+SiNW



50 μ m

PI+SiNW+Light

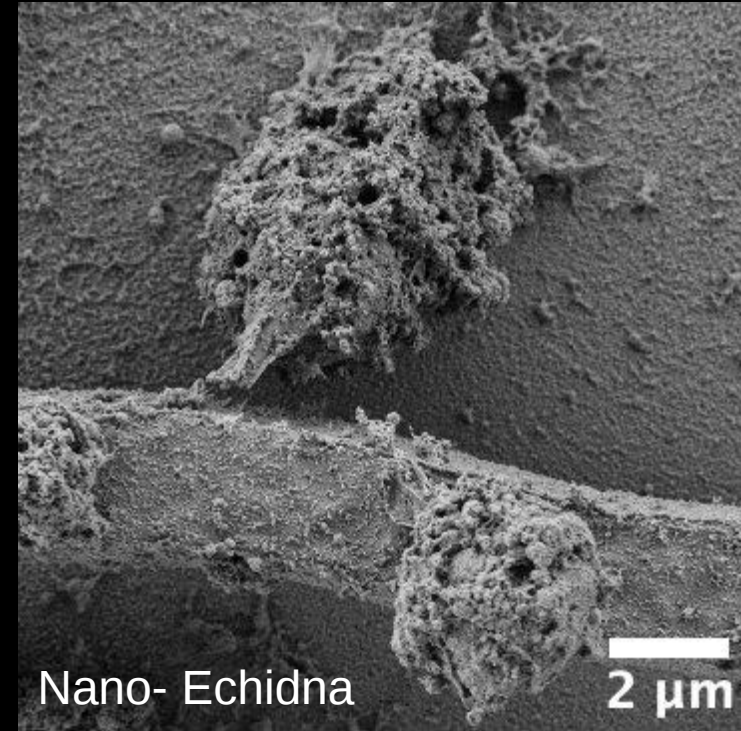
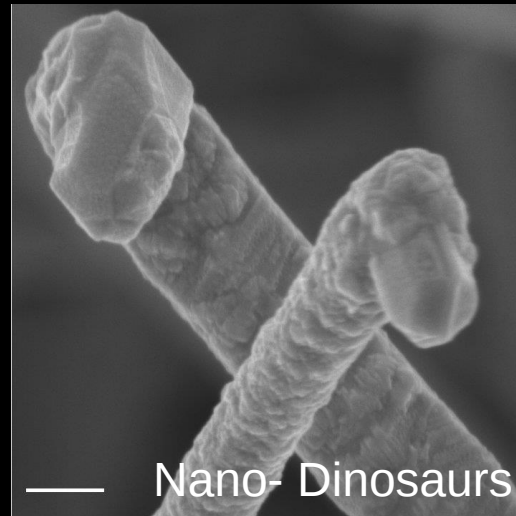
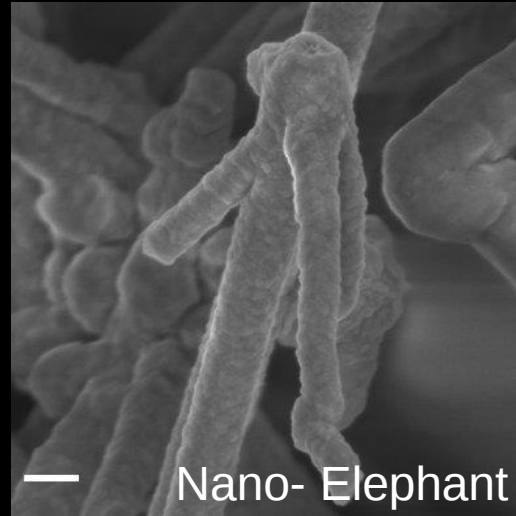
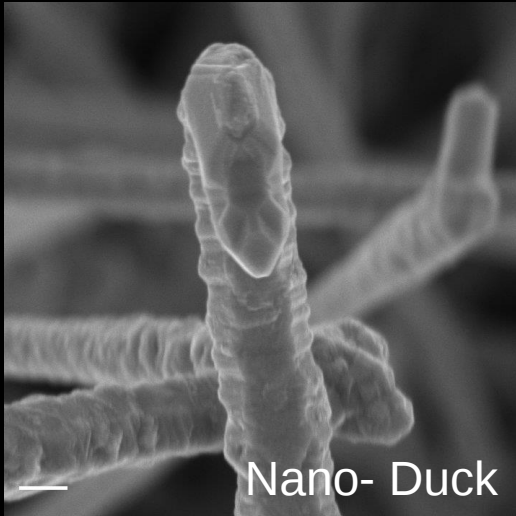


50 μ m

Conclusions

- We can employ different modulation to cell
 - Photothermal (intrinsic)
 - Optoelectronic (p-i-n)
 - Oxidative (n-i-p)
- Sub cellular resolution
- Biocompatibility
- Spontaneous internalization
 - Cells
 - Organoids

Our lab's nano-Zoo



Lab members:

Dr. Shiri Karni Ashkenazi

Shirley Yitzhak-David

Piotr Kucia

Tania Assaf

Layan Habib

Nitzan Dabush

Alexander Borodetsky

Luba Axelrod

Noa Cohen

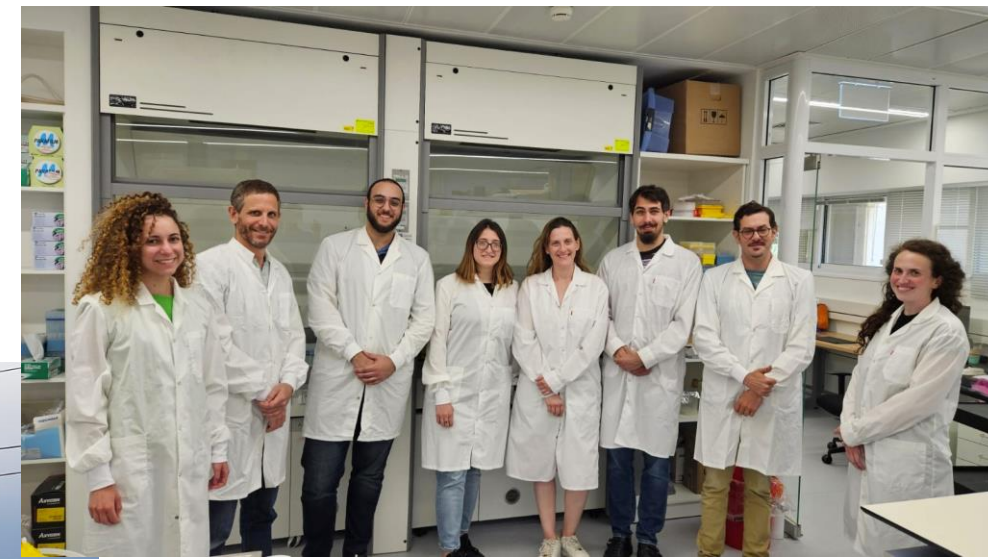
Nadi Hathot

Collaborators

Prof. Benny Elbaz @Northwestern

Prof. Francesca Santoro @RWTH-Aachen

Prof. Yin Fang @Tongji



TECHNION
Israel Institute
of Technology

Funding:



Co-funded by the
European Union



הקרן הלאומית למדע
المؤسسة الإسرائيلية للعلوم
Israel Science Foundation



Ministry of
Science and
Technology

