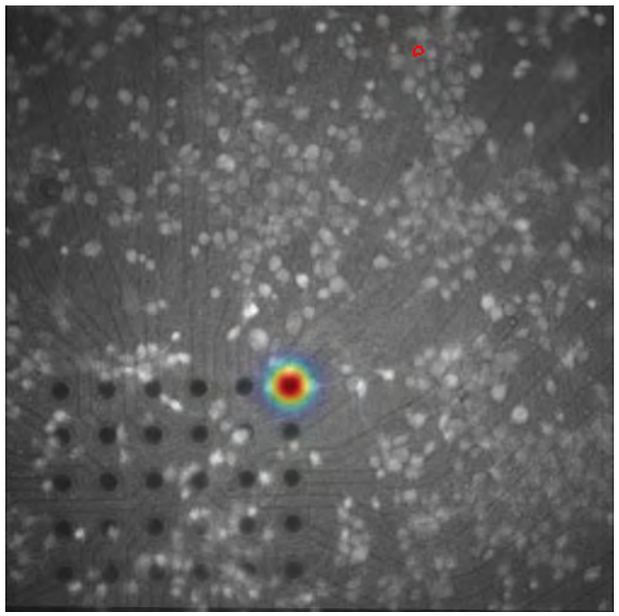
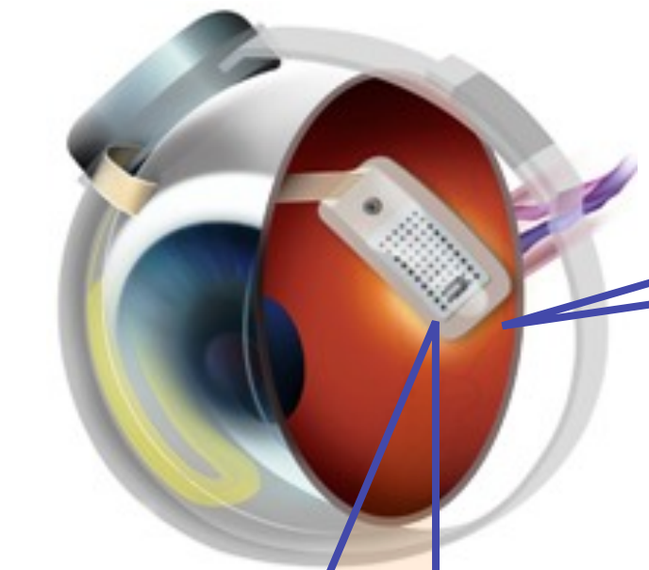
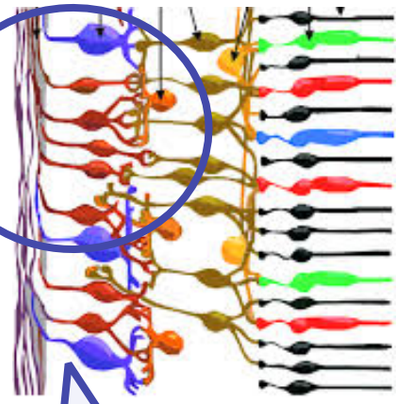


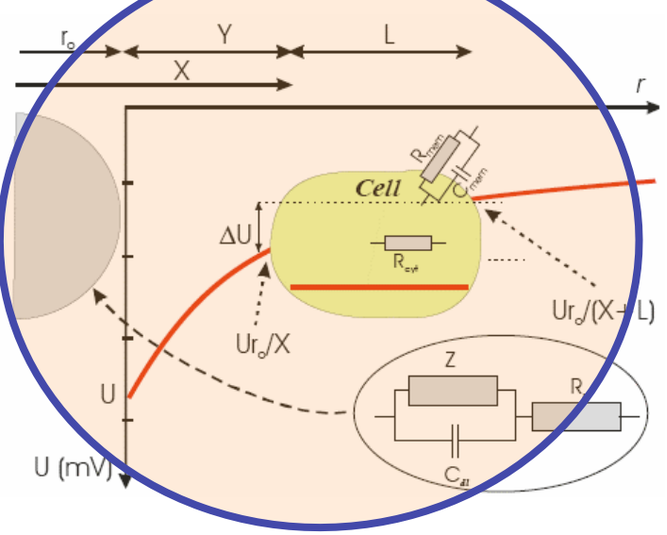
# Electrical and opto-electrical neuro-stimulation

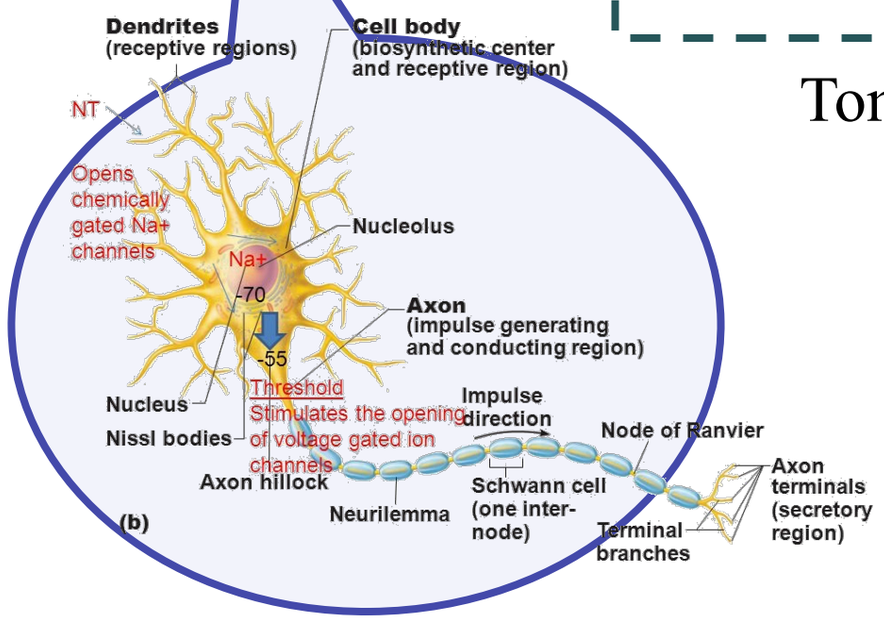
Yael Hanein, School of Electrical Engineering, Sagol School of Neuroscience

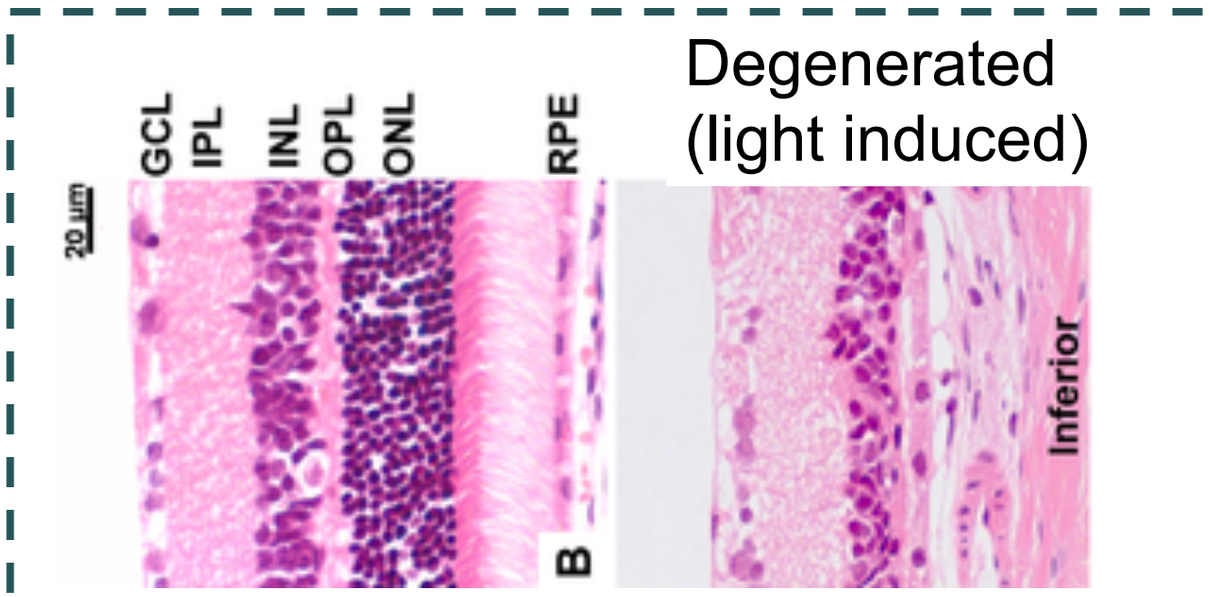
# Retina degeneration and electrical stimulation







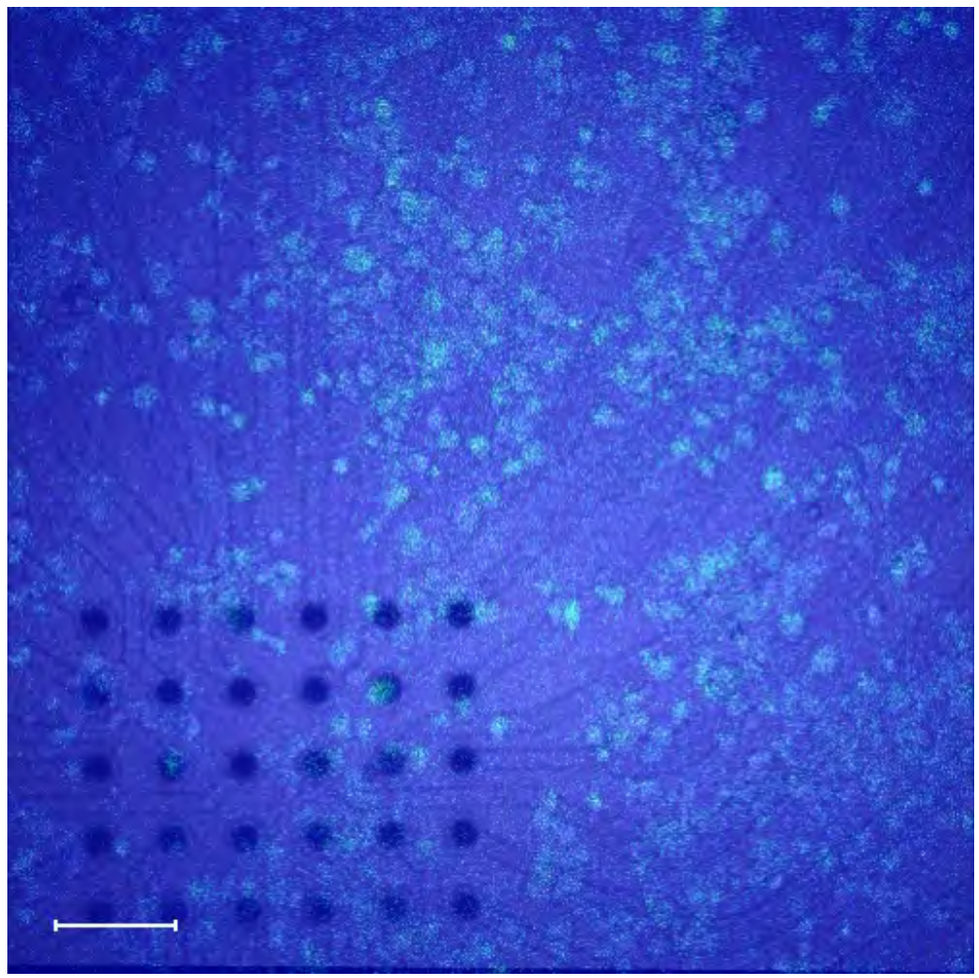

Tomita et al., PLoS ONE 4(11) 2009.

Understanding (Artificial) stimulation mechanism

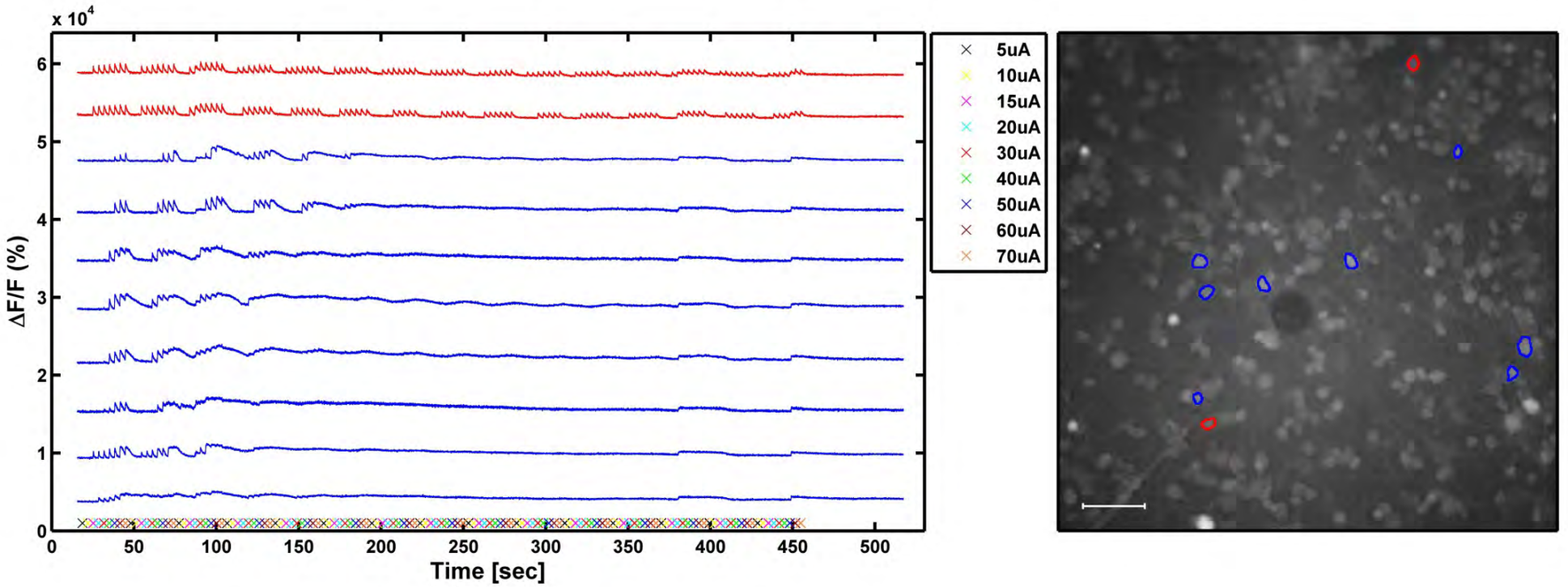
- Electrical (voltage gated channels)
- Thermal
- Chemical (Faradaic processes)
- Mechanical

Optimizing stimulation efficacy

- Resolution:
  - Stimulation parameters
  - **Electrode size and density**
- Energy
  - Electrode roughness



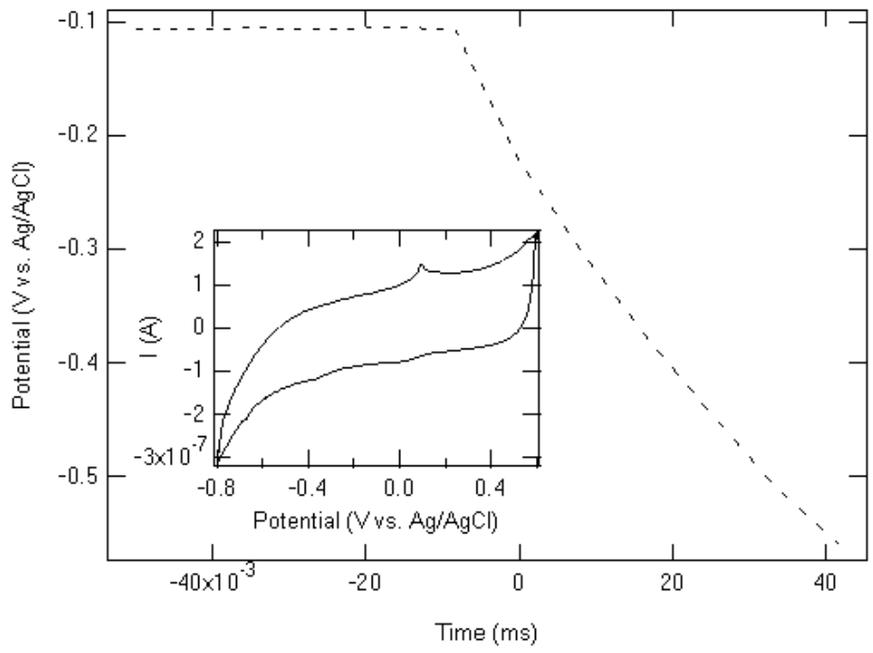
10 μm electrodes

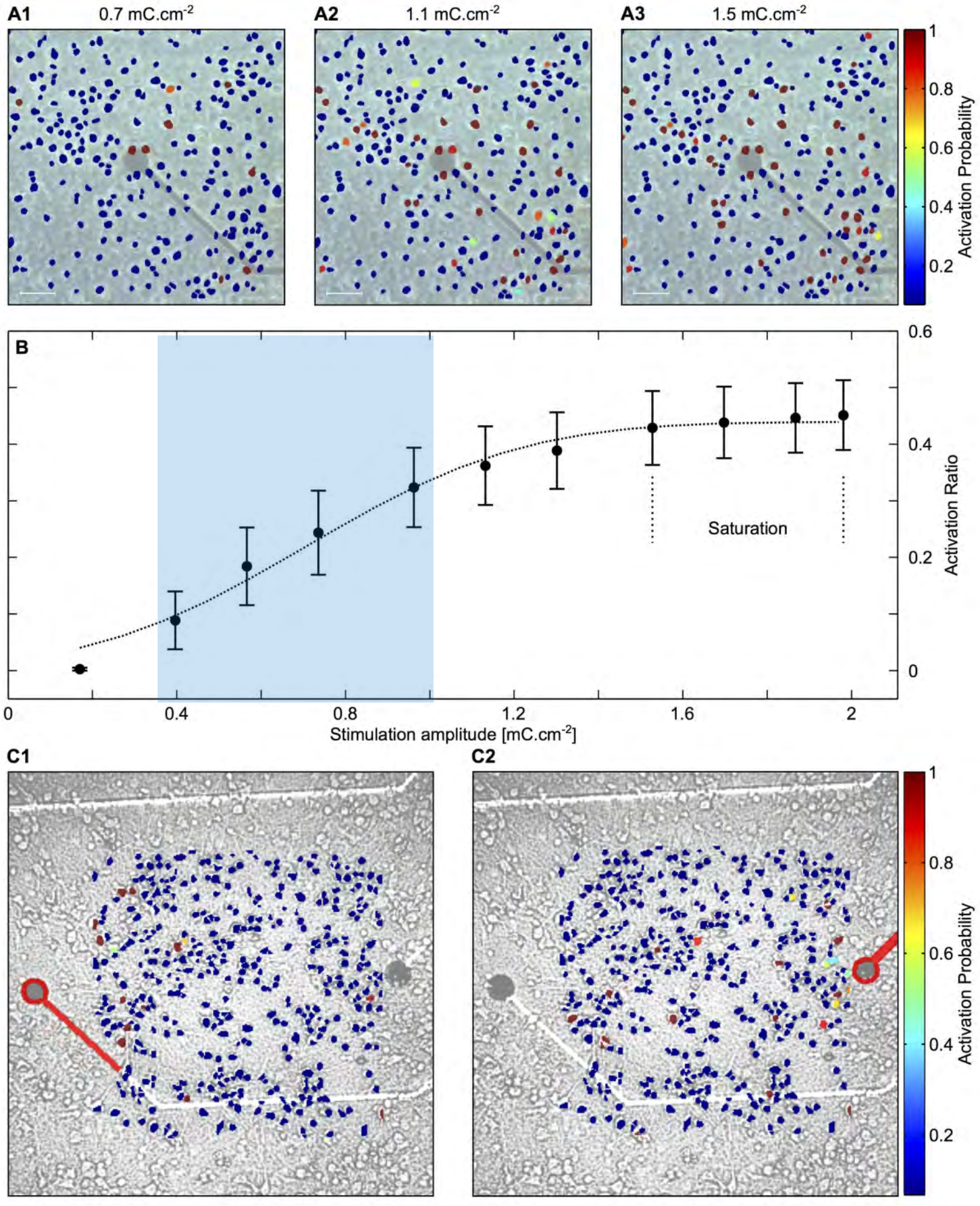





Electro-poration appears to take place well below electrode safe limits (60 μA, 0.4 ms,  3.5 mC/ $cm^2$)

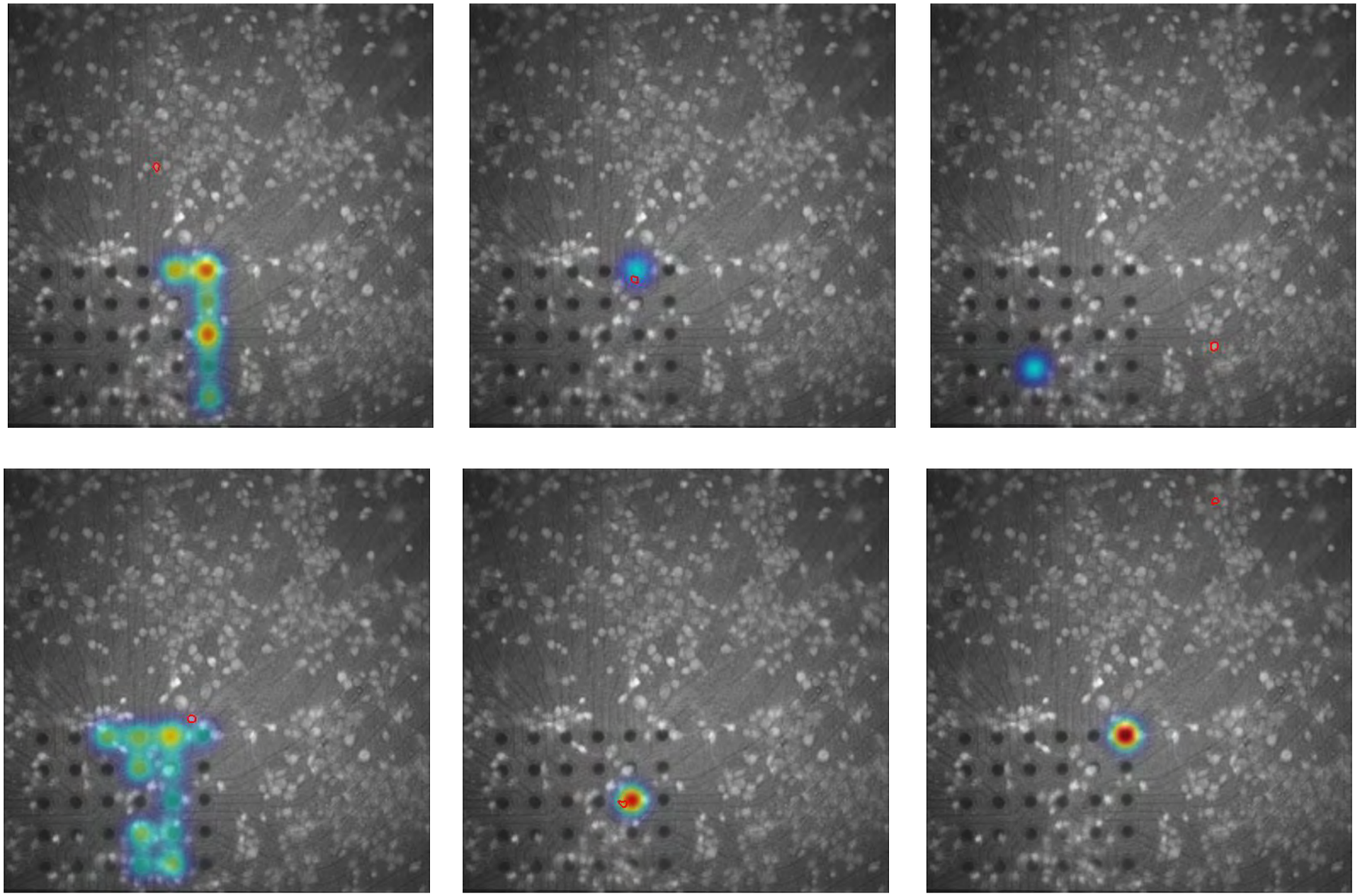
To be compared with TiN limit: 23 $mC/cm^2$



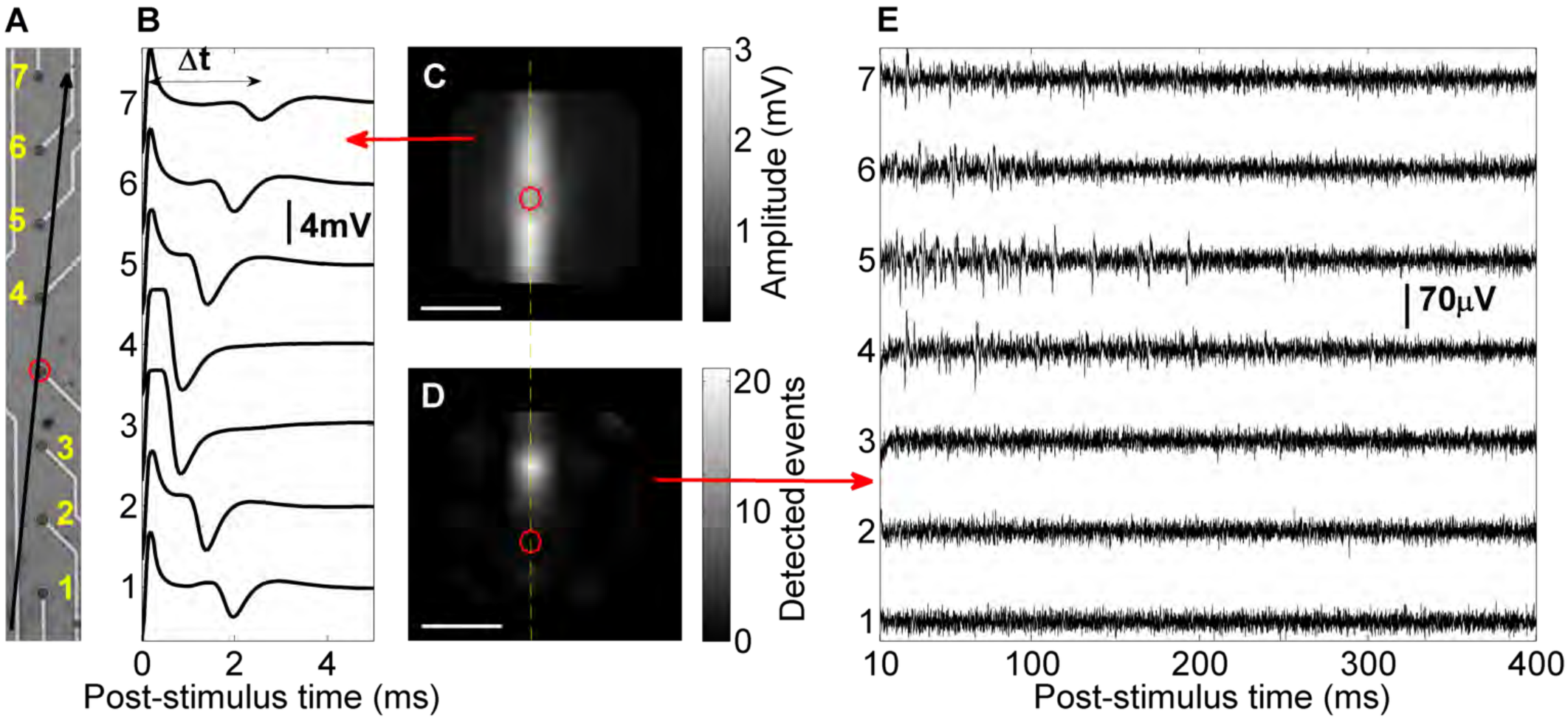



In vitro stimulation
0.4-1.4 mC/cm$^2$

# Neuron-electrode coupling



# Ex-vivo Chick Retina

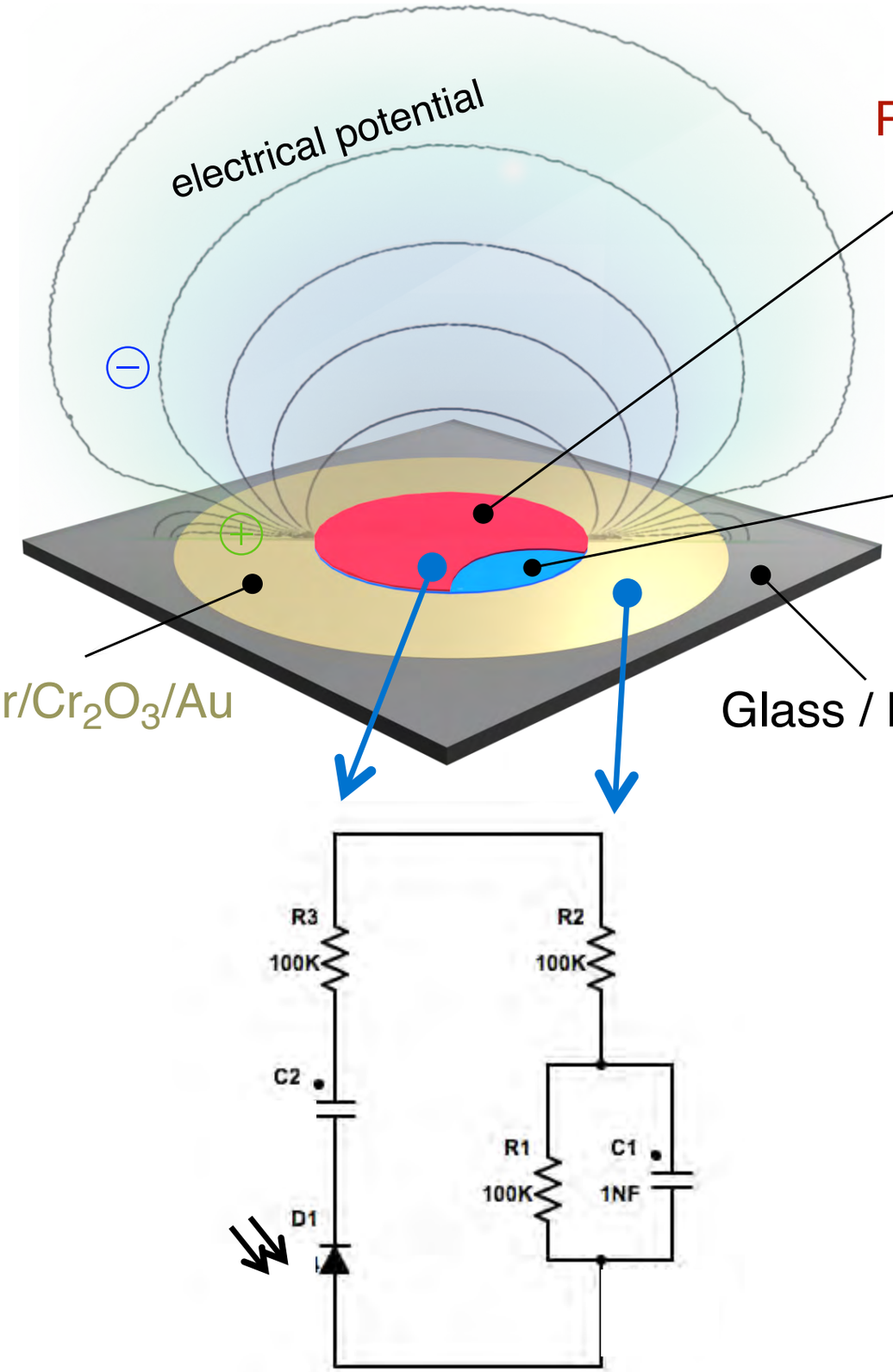



Direct

Indirect

DRP, GBY and Yael Hanein, J Neuro Sci Meth, 2017

# Semiconducting “Photocap”




Rand, Hanein, Głowacki,
Advanced Materials, 2018.

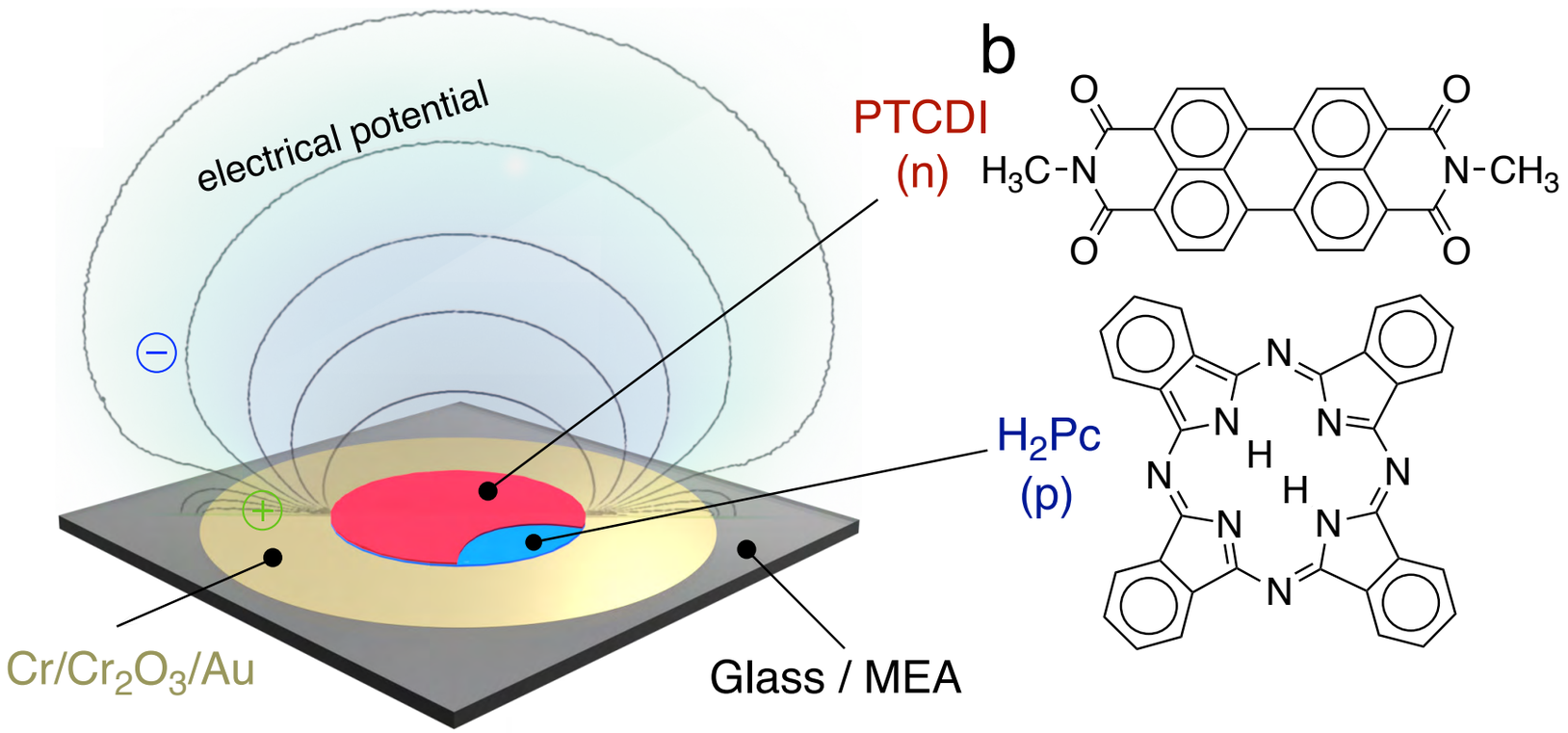
Solution/Ionic conduction

Interface

SC/Gold Electronic conduction

# Semiconducting organic pigments

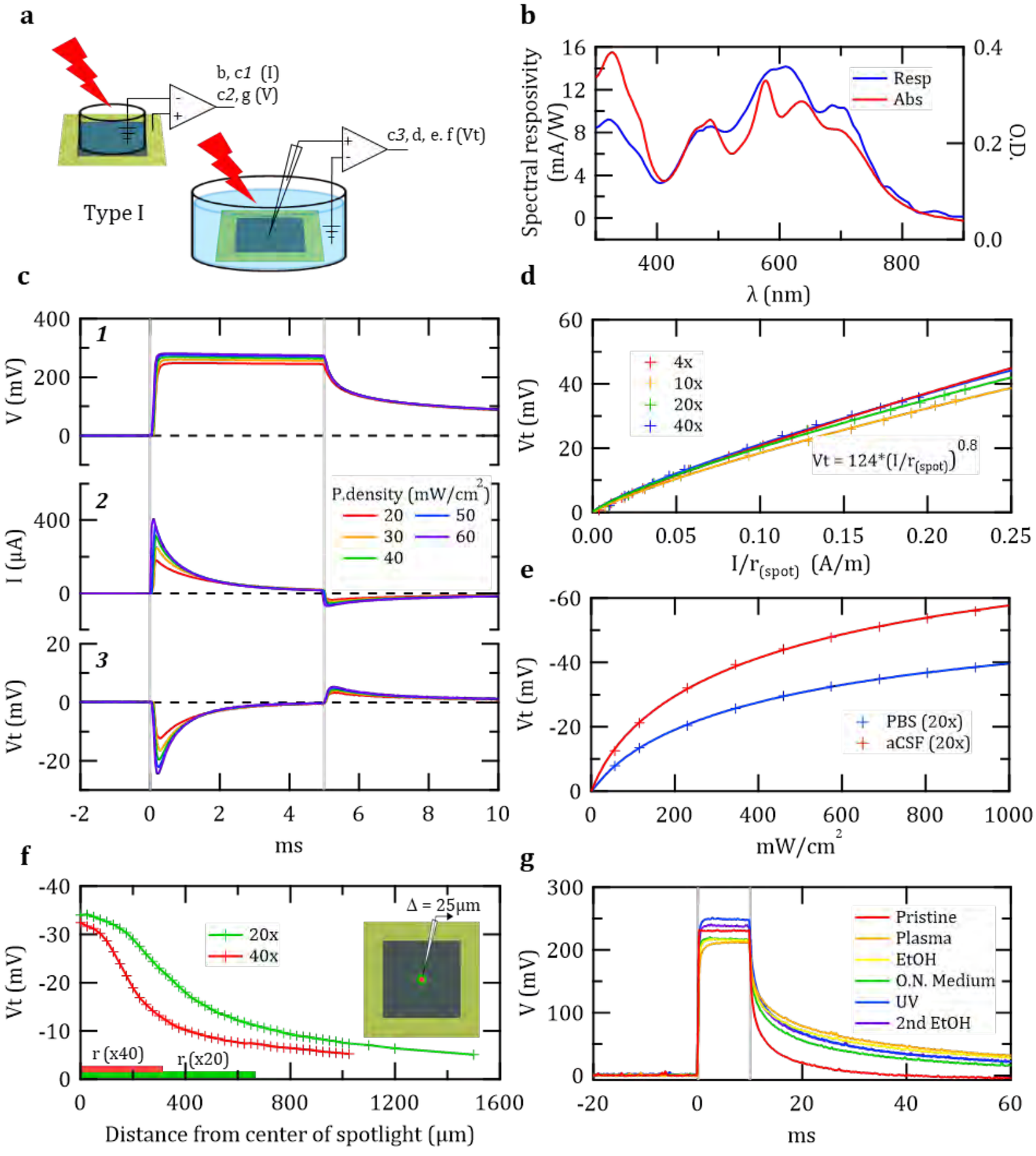
- Low cost
- Stable in aqueous environment
- Non-toxic, biocompatible
- Organic electronic (OLED, OPV, OFET)



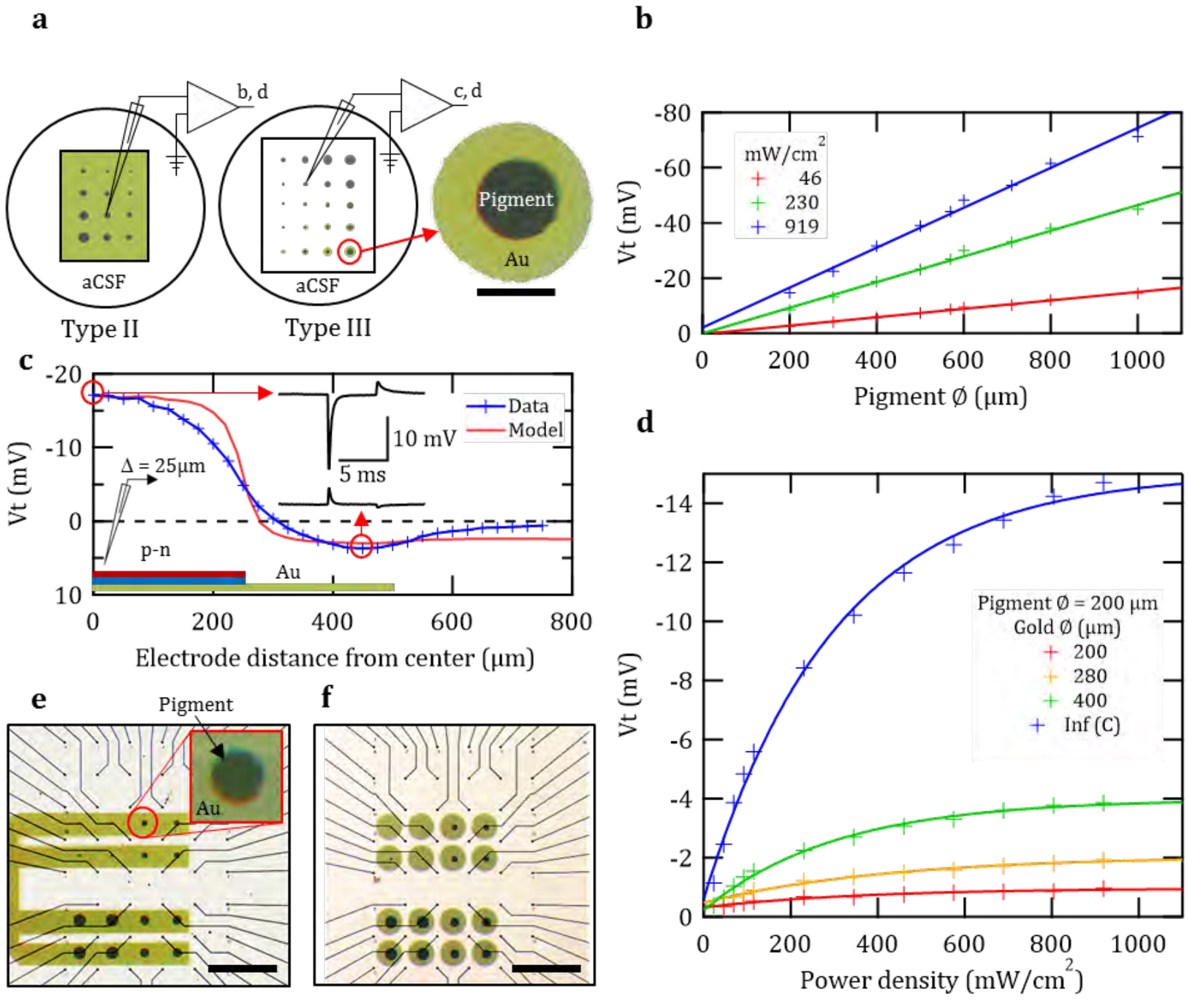

PTCDI (Pigment violet 29)

Phthalocyanine (Pc) Blue

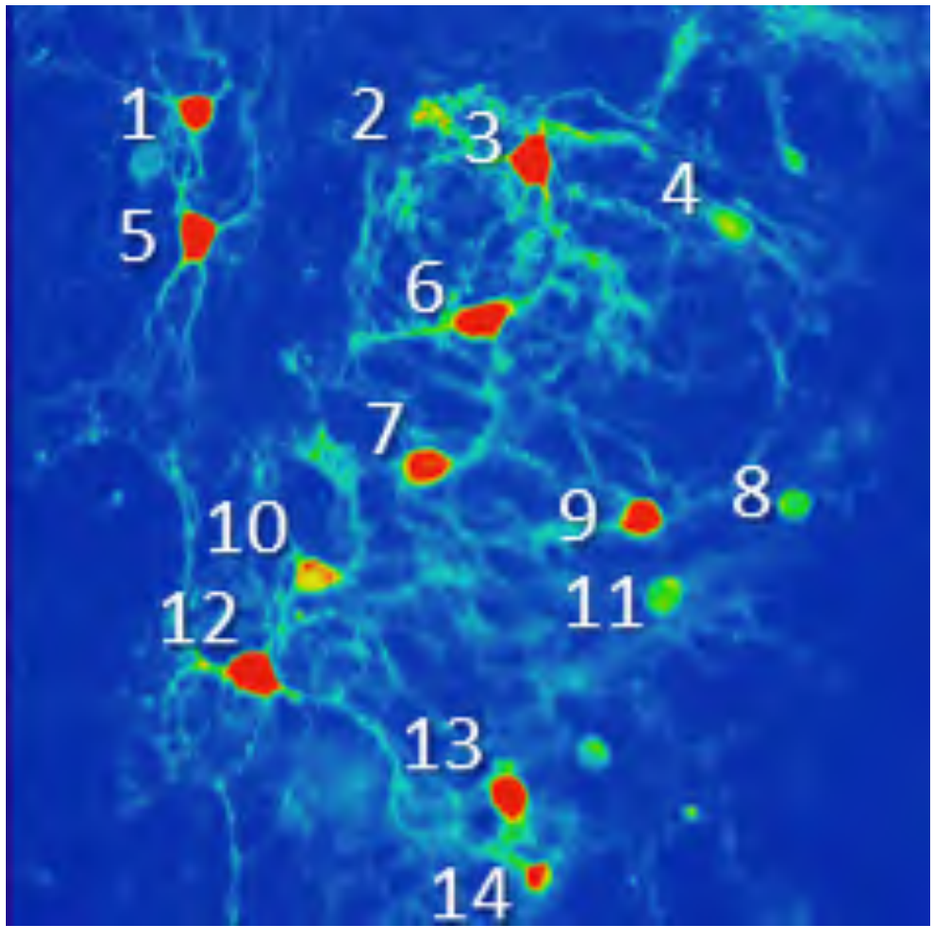
# Photoresponse of SC organic pigments



# Transient voltages for known stimulating currents

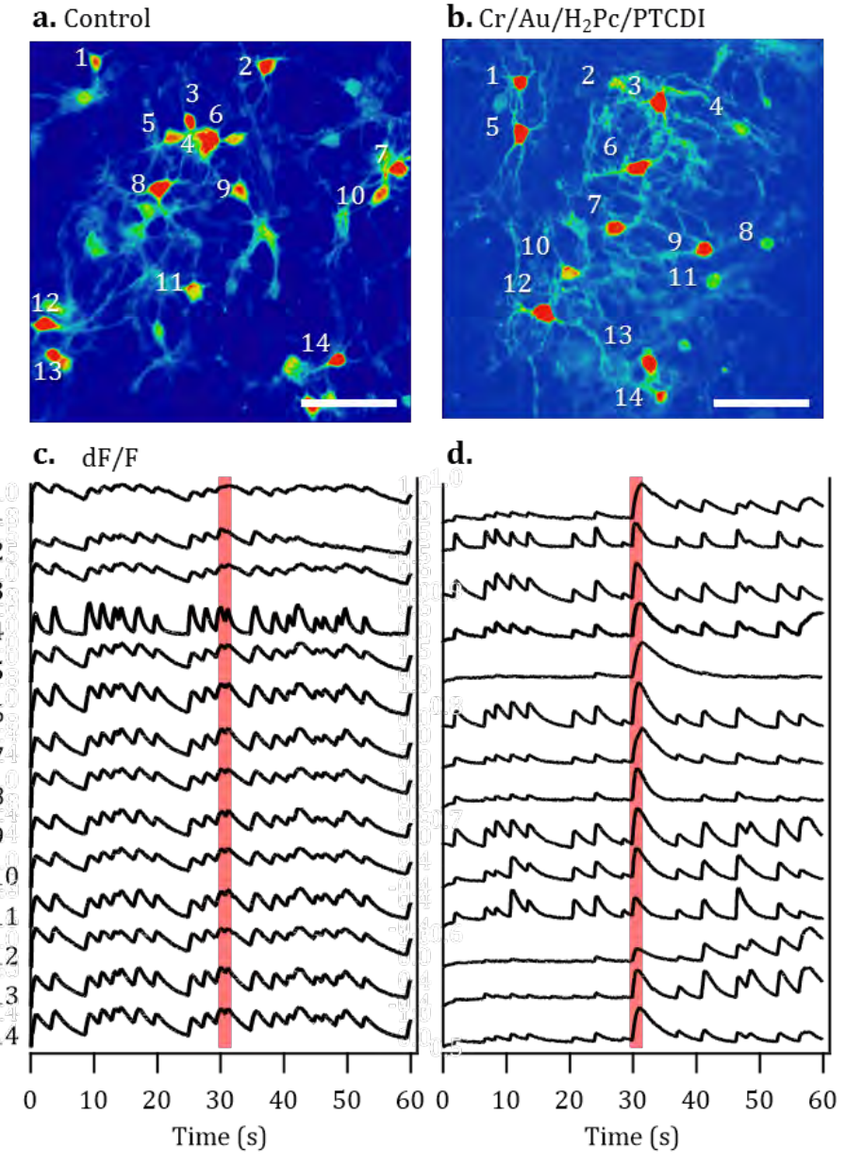


# Photo-stimulation of primary neural cultures




DIV 14 mice primary cortical neurons

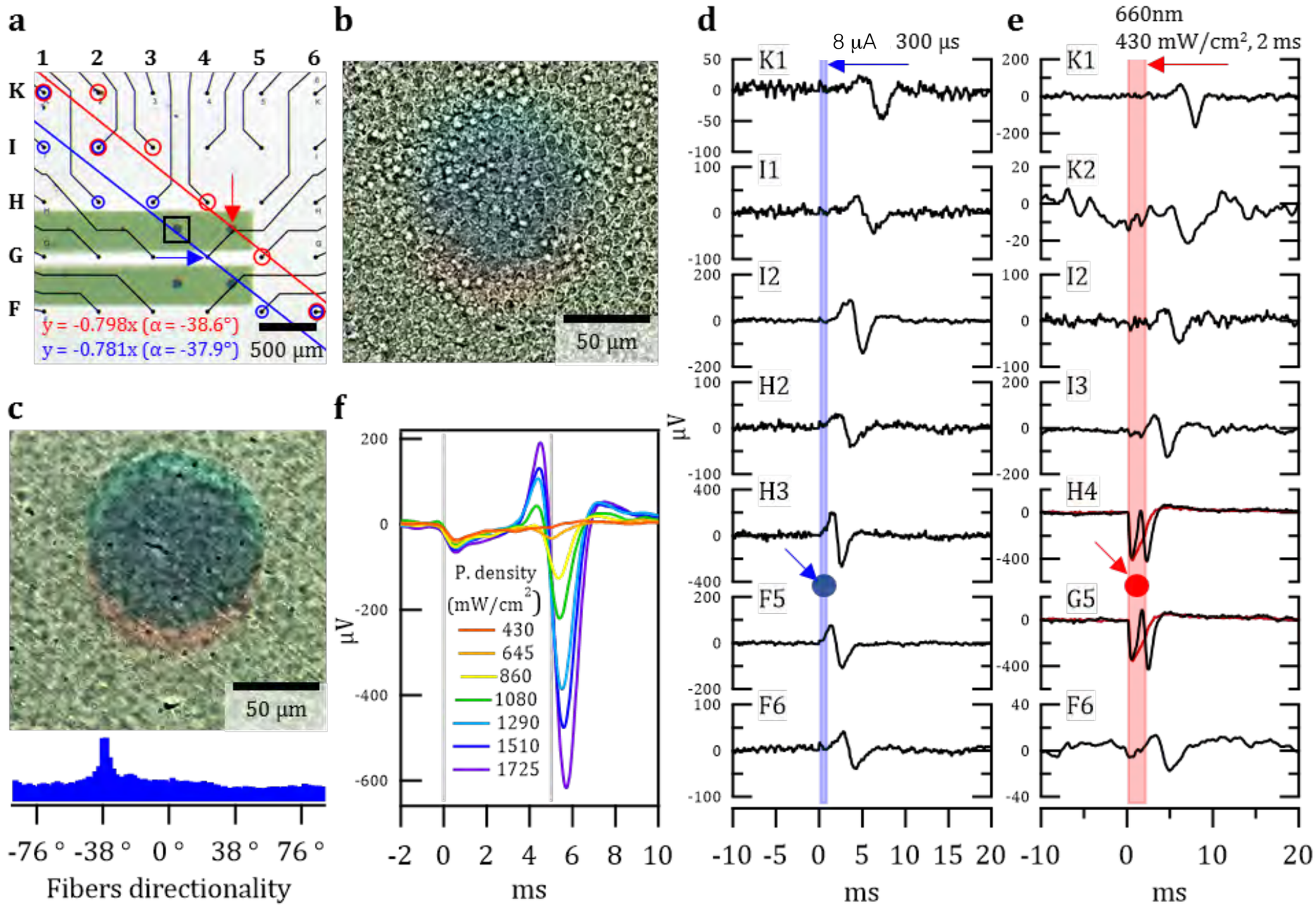
Relative fluorescence (dF/F) traces




Rand, Hanein, Głowacki, Advanced Materials, 2018.

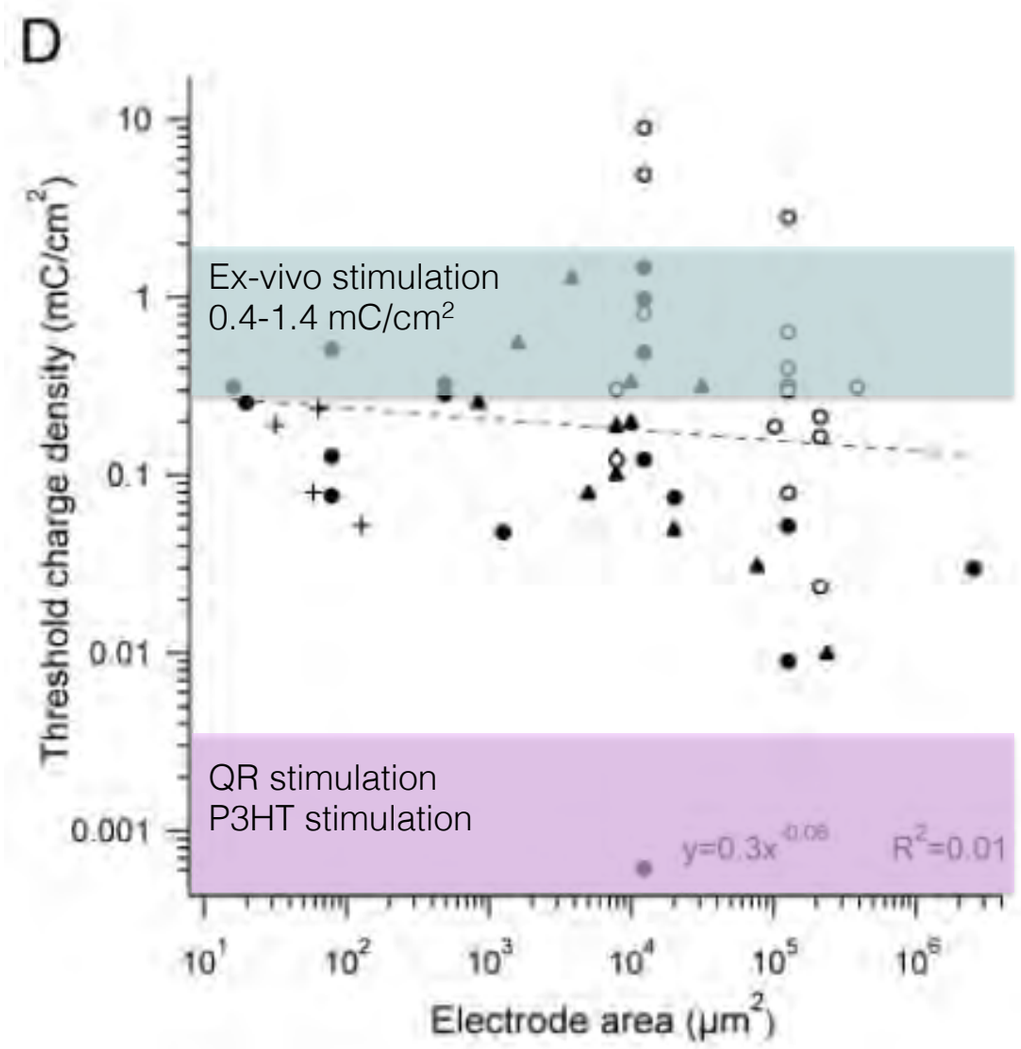
100 consecutive pulses (600 nm, 480 mW/cm$^2$, pulse duration 5 ms, interpulse interval 10 ms).

# Photo-stimulation of blind retina (Direct response)



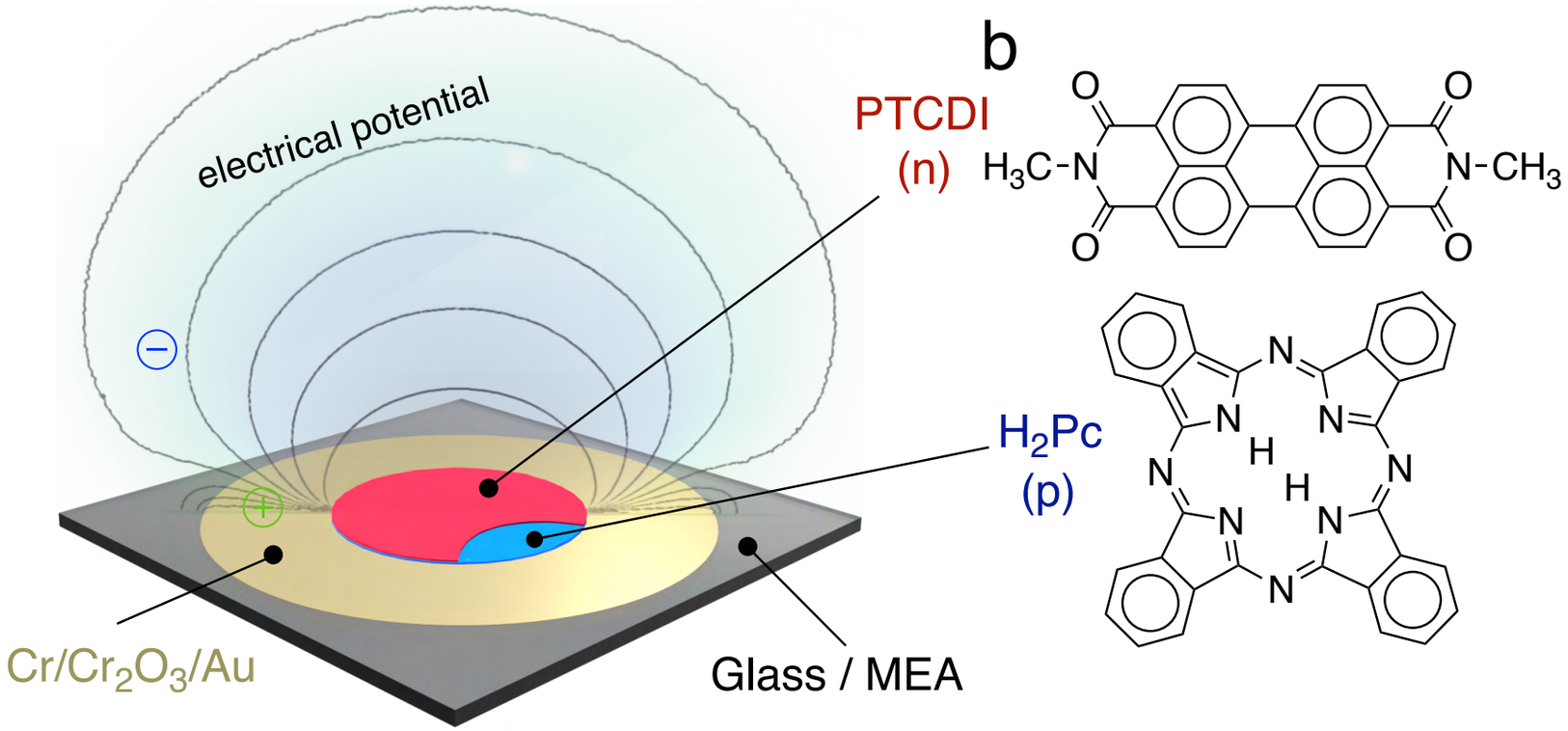

Rand, Hanein, Głowacki and co-workers, Advance MAterials, 2018.

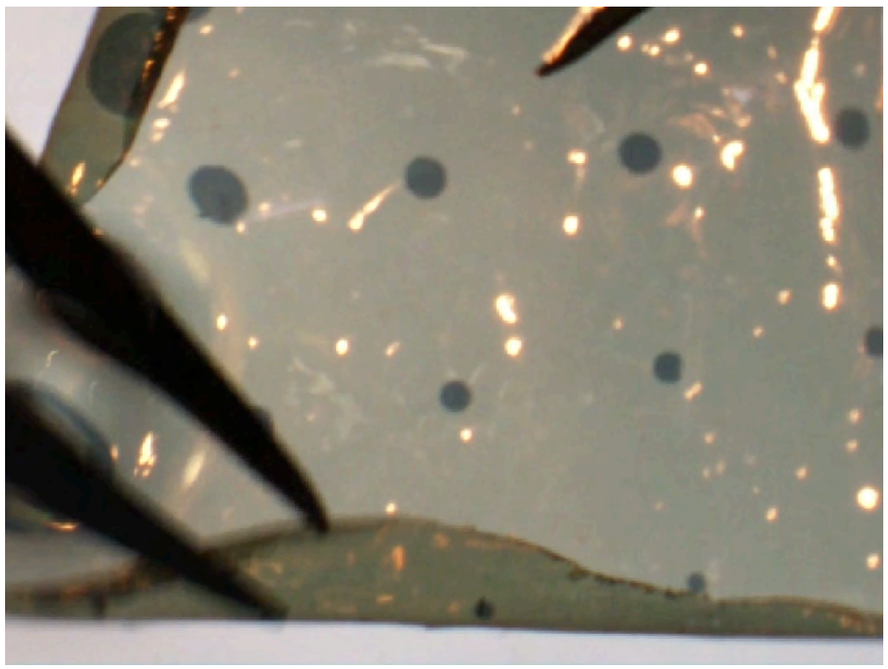
# Charge Density Values



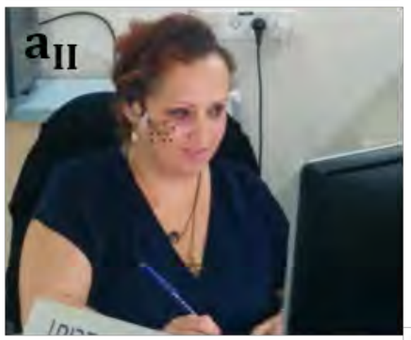

| | Raz Prag et al., | Rand et al., | Wallach et al., | Rand et al., | Rand et al., |
|---|---|---|---|---|---|
| | Chick Retina | Chick Retina | Culture-elec | Culture | Chick Retina |
| | Electrical | Electrical | Electrical | Optical | Optical |
| Illumination Intensity (mW/ cm2) | | | | 480 | 130 |
| Pulse amplitude (uA) | 100 | 8 | | 3200 | 86.66666667 |
| Pulse duration (us) | 60 | 300 | | 5000 | 2000 |
| Pulse number | | | | 50 | 1 |
| Electrode diameter (um) | 30 | 30 | | 10000 | 200 |
| Charge density mC/cm2 | 0.8492569 | 0.33970276 | 0.6 | 0.8 | 0.552016985 |

Sekirnjak et al., 2006



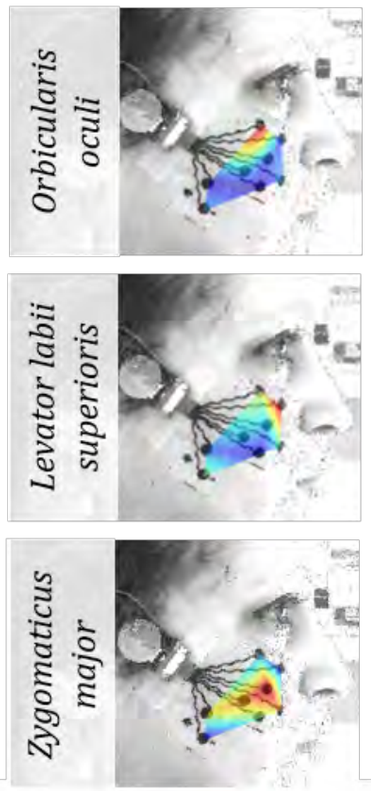



80 nm p-n
10 nm Au
10 μm Silk

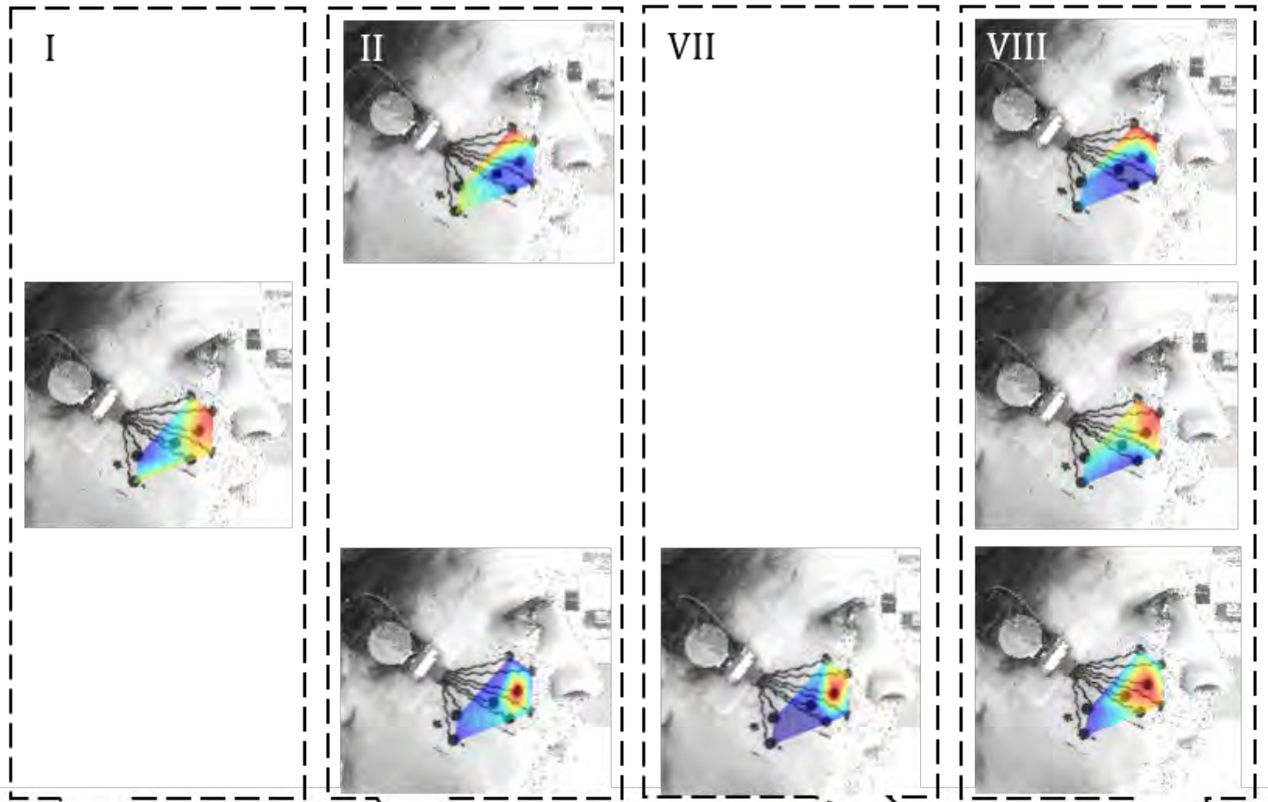





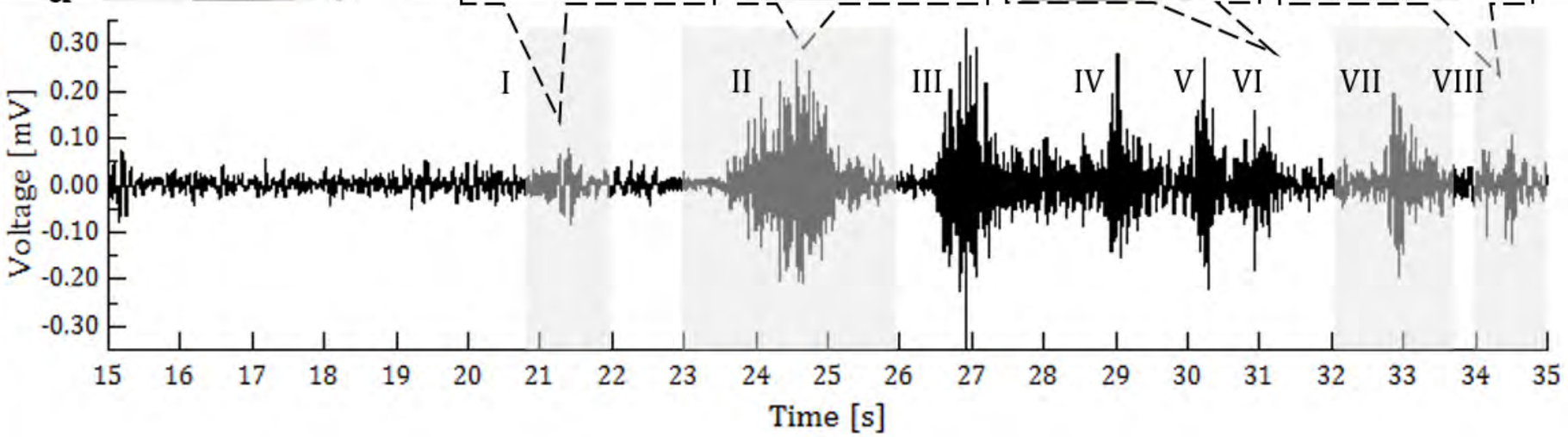
**b** Training (Wireless)




**c** Real time recordings




**d**



# Charge/phase and charge density requirements for neural stimulation

Lessons from in vitro and ex vivo studies

- Activation through electrical stimulation targets a very particular subset of cells. Most likely to be stimulated are cells with processes crossing close to the electrode or cells positioned right at the electrode site
- Activation is statistical in nature with higher amplitudes/durations recruiting more elements – not necessarily more distant elements
- Better coupled neurons are stimulated at thresholds which are electrode size dependent
- Glia activation and electroporation
- Typical values are in the 0.5 $nC/cm^2$ range

Photo-sensitive materials offer exciting opportunities to light-up neurons in a safe manner

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