ScuDo

Scuola di Dottorato ~ Doctoral School

WHAT YOU ARE, TAKES YOU FAR

XXXIII Cycle

Probes with switchable optoelectronics for simultaneous readout and local manipulation of in vivo neural activity

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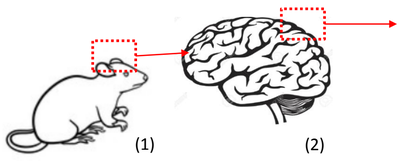
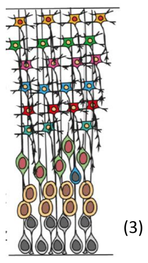
Supervisor: Andrea Lamberti, Fabrizio Pirri

1.Research context and motivation

Neuroscience aims at understanding the role of neurons inside networks. Neurons in the cortex are arranged in layers

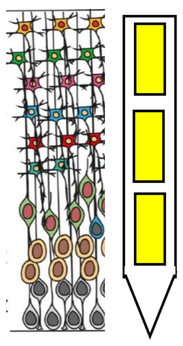




Current methods of investigation of in vivo neural networks rely either on electrical readout or manipulation with light:

Electrical readout with electrodes integrated on silicon tip [1]

Voltage measure of neural extracellular action potential. Measure due to double layer capacitance formation at electrode interface



OR

Optical deactivation with light through fiber [2], [3]

Neurons genetically modified with light sensitive proteins. Protein inhibits neural activity when activated by light

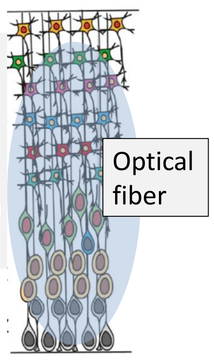


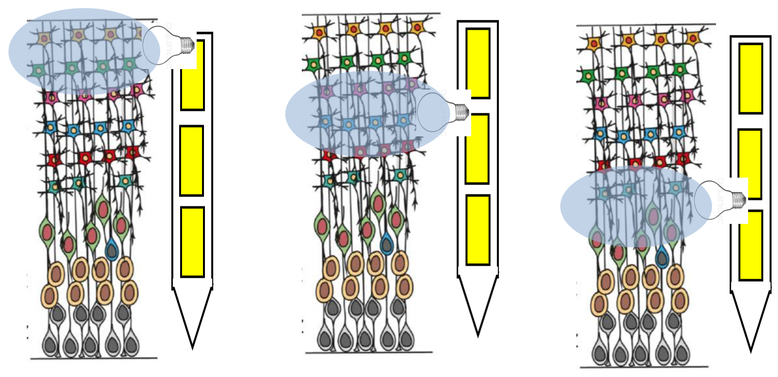
Image sources:
(1): adobestock.com
(2): https://www.123rf.com/photo_50554965_stock-vector-vector-black-brain-icon-on-white-background.html
(3): Journal of Experimental Neuroscience Volume 12: 1–12 (2018)

2.Addressed research questions/problems

How do neural signal travel across cortical layers? What's the function of each cortical layer?
Current devices allow **either electrical readout** of large number of neurons (with single neuron resolution) **OR optical deactivation of several layers** → this only allows probing how network communicates when it's **entirely ON or entirely OFF**

Goal: single selectable cortical layer deactivation simultaneously with readout to monitor how network communicates when **selected layers are OFF**.

Device: We fabricate devices for readout of networks and simultaneous optical deactivation of portions of it

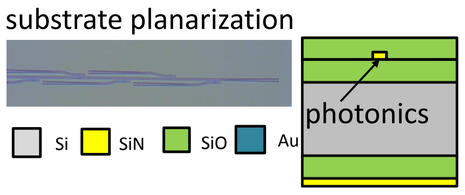


Experiment: We aim at deactivating separate single cortical layers while recording how the neural electrical signal path changes (through which layers it propagates) to infer single layer function

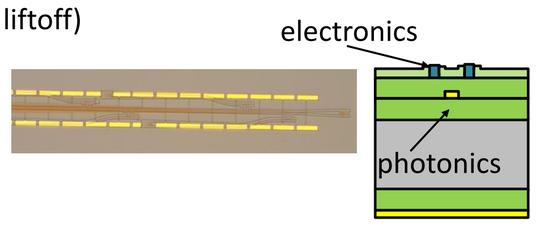
Adopted methodologies

Readout achieved with micro/nanofabricated gold electrodes on silicon tip.
Optical manipulation obtained by integrating nanophotonic circuits buried below the readout electrodes [4].

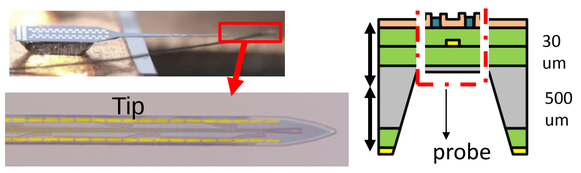
1. Patterning of photonic circuits
SiO2-SiN on 4 inch wafer. Pattern (electron beam lithography + dry etch). Cladding of photonics with SiO2 and substrate planarization



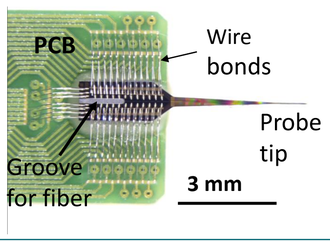
2. Patterning of electronic circuits
Electronics alignment to photonics, patterning (electron beam lithography + liftoff)



3.Circuit integration on tip
combination of dry top wafer etch + wet bottom wafer etch



4.Connection to electronics/laser
Wire bonding on printed circuit board (PCB).
Photonics: fiber – waveguide edge coupling



List of attended classes

- 01SAYRV Metamaterials: Theory and multiphysics applications (26/09/2018, 20 h), Communication (30/09/2018, 5 h), 03LCLRV Epistemologia della macchina (20/06/2019, 20 h), 01RISRK Public speaking (30/09/2018, 5 h), 01SYBRV Research integrity (15/11/2018, 5 h), 01SAYRV Self Management (19/06/2019, 5 h), 02RHORK The new Internet Society (17/10/2018, 5 h), 01SWPRV Time management (15/11/2018, 5 h)
- Ongoing classes: 01TCPRV Nano and molecular electronics (40 h), 01SHORV Nano & Quantum Computing (40 h)
- External seminars – 24 h
- External research performed at Molecular Foundry, Lawrence Berkeley Laboratory

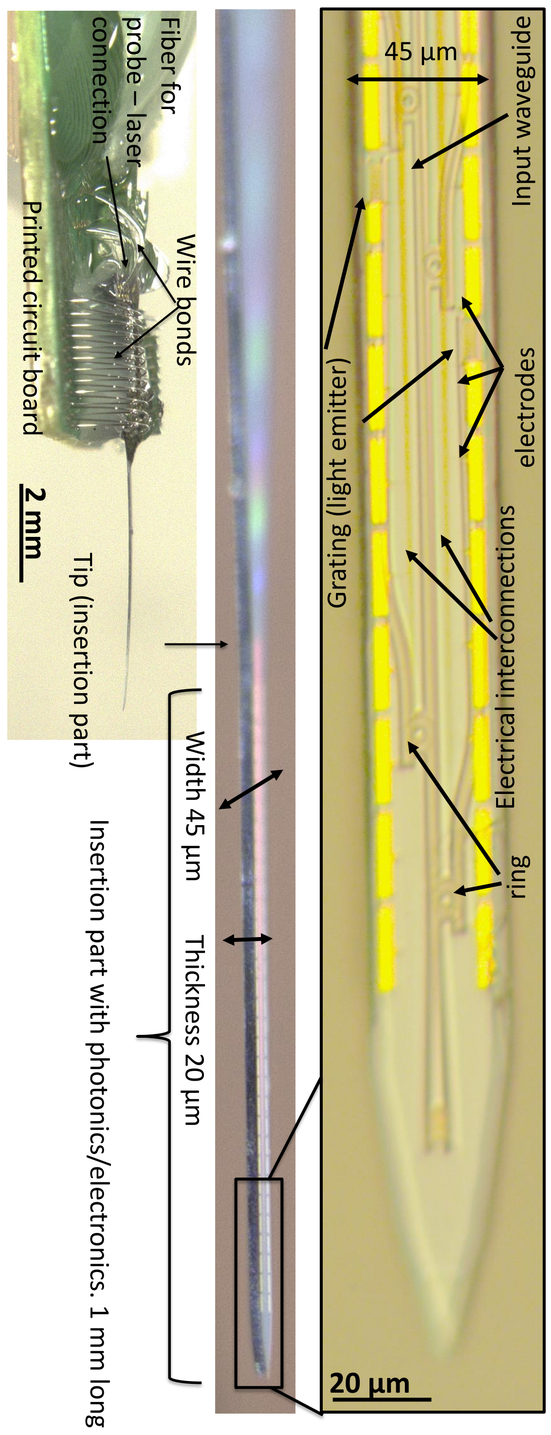
Submitted and published works

V Lanzio er Al., "*TiHigh-density electrical and optical probes for neural readout and light focusing in deep brain tissue,* J. Micro/Nanolith. MEMS MOEMS 17(2) 025503 , vol. 17, no. 2,

References

[1]: *J. Neurophysiol.* **111,** 1132–1149 (2014)
[2]: *Nat. Rev. Neurosci.* **18,** 222–235 (2017)
[3]: *Neuron* **86,** 92–105 (2015)
[4]: *J. Micro/Nanolith. MEMS MOEMS 17(2) 025503 , vol. 17, no. 2, 2018*

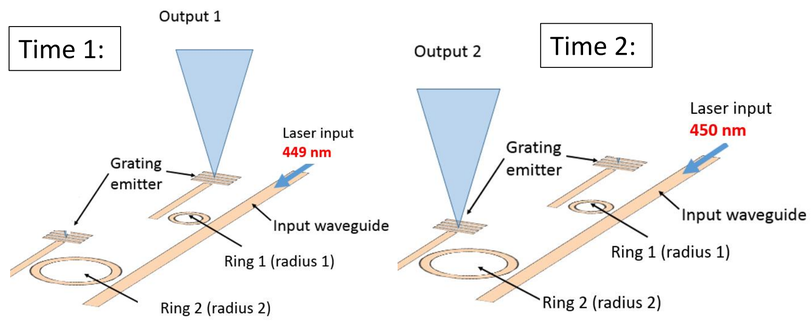
4.Novel contributions



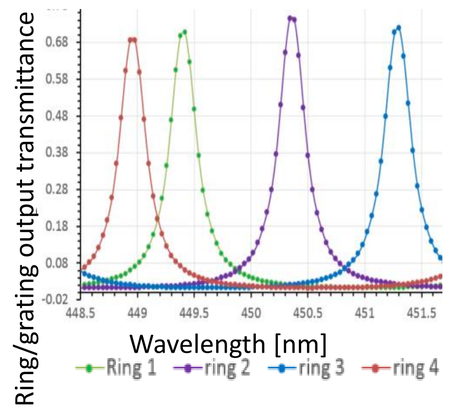
→ **Device miniaturization** for reduced brain damage

→ **High density electronics** (64 electrodes). Each electrode can record one neuron

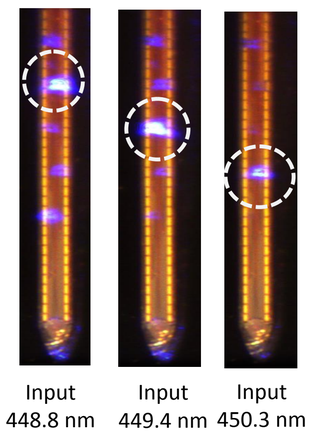
→ **Integration of switchable photonics**
To shine light in different areas around the tip (to deactivate neurons around selected tip areas) we integrate photonic switches (rings) terminated by light emitting gratings. Selection of a switch based on laser input wavelength: a specific wavelength resonates only with a ring with specific radius. Only illuminated neural regions are deactivated



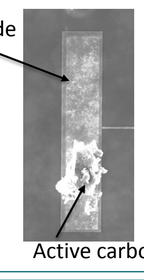
Rings resonance depends on ring radius



Light output location selection on tip for different input wavelengths

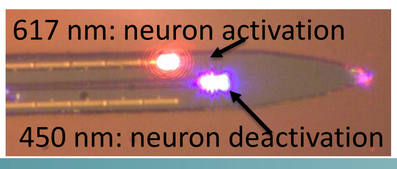


→ **Carbon based materials on electrodes**
Additional post processing device optimization by deposition of graphene or activated carbons on electrodes for better biocompatibility and higher signal to noise ratio



5.Future work

- In vivo test of probe for selective deactivation of cortex lasers
- New designs of photonics based on first experiment feedback →
- Optimization of techniques for deposition ofcarbon based materials on electrodes and in vivo test



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