Optoelectronic neural probes with passive light switching optical circuits: light control in deep brain tissue

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Abstract- One of the main challenges of our century is to understand how the brain works and how the activity of neural cells in networks drive our behavior. In order to study neural networks, in vivo neuroscience experiments rely either on electrophysiology or on optogenetics. The first experimental approach consists in the measurement of electrical signals fired between neurons. Optogenetics, instead, allows inhibiting or enhancing neural activity by shining light inside brain tissue [2]. Michigan neural probes [1] are invasive devices which integrate passive or active sensors; when inserted into the brain of a living animal, they can measure or act on neural activity. Devices that combine both electrical and optical sensors allow the simultaneous recording and manipulation of brain activity. To advance our understanding of neuroscience, it is necessary to scale down neural probe dimensions (less insertion damage) while increasing the number of sensors [3]. Another desired characteristic is being able to activate/deactivate desired brain areas by controlling light output location in the device [4]. In this regard, at the Molecular Foundry, we fabricate neural probes that integrate both optical and electronic circuits with a reduced footprint. In particular, optical circuits allow passively turning on or off light. This is achieved thanks to the integration of add-drop ring resonators [5], which act as passive optical switches. Three benefits are obtained: ring resonators allow choosing the location where light is extracted inside brain tissue (i); ring resonators, since passive, do not generate heat (ii); ring resonators have a low footprint (<20 um width). Optical circuits are then integrated with electronic ones to enable electrophysiology measurements. The integration, performed in the same device, is made onto two separated layers and allows obtaining a high number of sensors (up to 64 electrodes and 24 light extraction points per tip) with small probe dimensions (tip width < 50 um, which is a value smaller than what is presented in the current state of the art). We expect, thanks to these devices, to be able to record and simultaneously manipulate neural activity from large groups of neurons. The combination of both electrical and optical circuits, small device dimensions, high number of integrated sensors and feasibility of passively controlling light output location in deep brain tissue allows achieving a more advanced level of control inside the brain.

[1]: Zoltan Feteke Recent advances in silicon-based neural microelectrodes and microsystems: a review, Elsevier, 03-2015

[2]: Edward S Boyden, Feng Zhang, Ernst Bamberg, Georg Nagel & Karl Deisseroth, Millisecond-timescale, genetically targeted optical control of neural activity, Nature Neuroscience 8, 1263 - 1268 (2005), doi:10.1038/nn1525

[3]: Gyorgy Buzsaki et Al. Tools for Probing Local Circuits: High-Density Silicon Probes Combined with Optogenetics Neuron 86, April 8, 2015 2015 Elsevier

[4]: Massimo Scanziani & Michael Häusser, Electrophysiology in the age of light, Nature 461, 930–939 (15 October 2009), doi:10.1038/nature08540

[5]: Alexander Gondarenko, Jacob S. Levy, and Michal Lipson, "High confinement micron-scale silicon nitride high Q ring resonator," Opt. Express 17, 11366-11370 (2009)

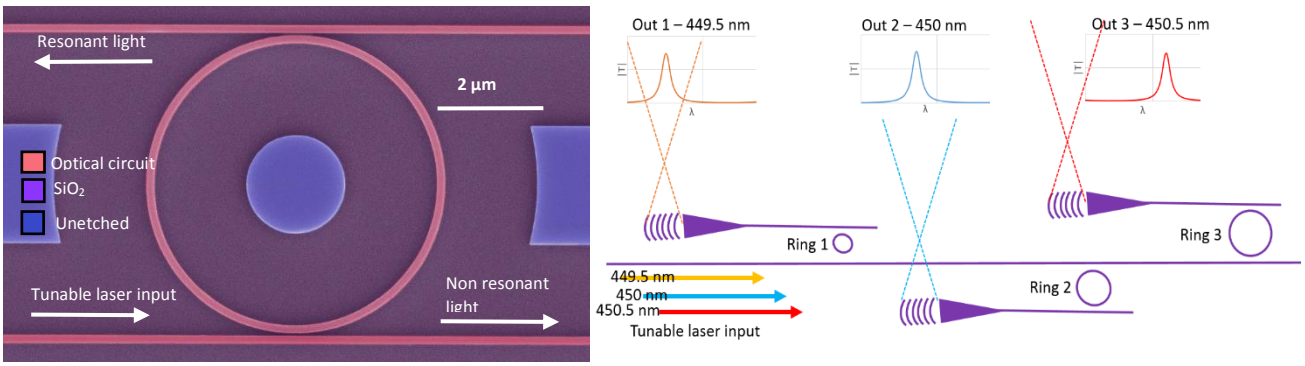

Figure 1: Optical circuits. (left): Add – drop ring resonator, SEM false color image. (right): Representation of optical circuit with input waveguide, ring resonators and diffractive optical elements (focusing gratings).

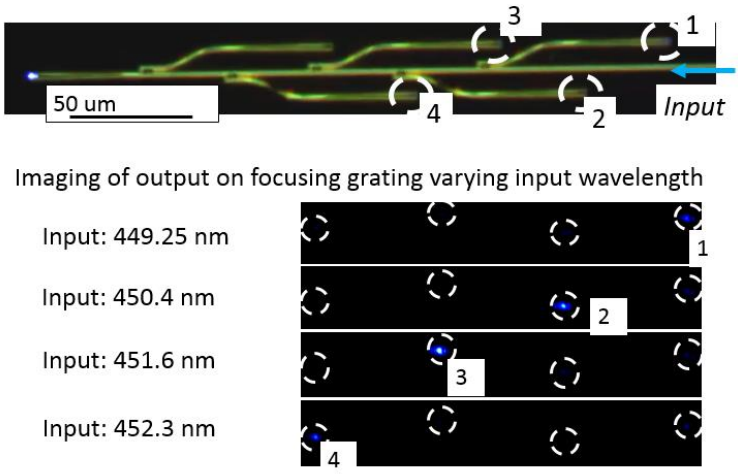

Figure 2: Passive light switching in optical circuits, design for neural probe. Light is extracted from different locations depending on the input wavelength.

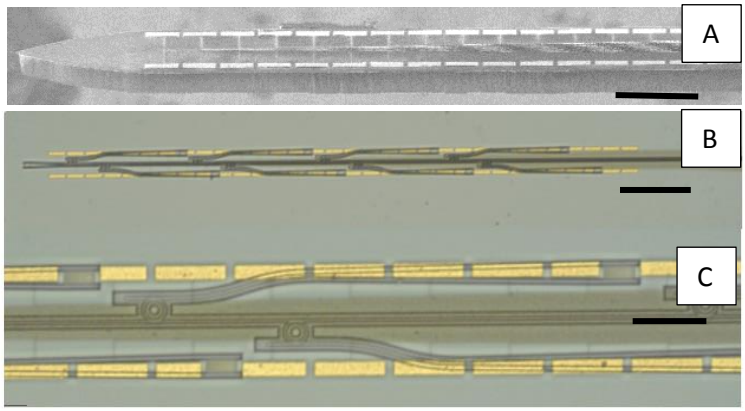

Figure 3. (A) Neural probe with 64 electrodes (scale bar: 50 um). (B): Integration of optical circuits with passive optical switches on neural probe (scale bar: 50 um) and (C) zoom showing electrodes and rings (scale bar: 25 um).