High density, multifunctional neural probes for massively parallel read-out and control

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Abstract-In order to advance neuroscience in vivo experiments, it is necessary to interface neural networks at a single cell level doing simultaneously electrical recordings, pharmacological manipulation, and optogenetic intervention, while minimizing brain tissue damage. Many examples of Michigan neural probes *[1]* exist: high density of electrodes neural probes *[2]* or of multifunction integration *[3]* probes. Ideally though, a simultaneous presence of high density of components, multifunction integration, and micrometric dimensions is required.

High density electrical probes have been fabricated (Fig. 1): probes have 64 pads in the 45 µm wide and 15 µm thick shank. Impedance measurements of pads in saline yield 220 ± 30 KΩ for electroplated recording electrodes (Fig. 2). Measurements performed in vivo on rat's cortex will be presented.

Probes with SiO_2-Si_3N_4 ridge single mode waveguides (cross section: 320 nm x 160 nm) and focusing gratings are fabricated. Waveguides are patterned using electron beam lithography. As for electrical probes, probes are thinned from the wafer backside in KOH and their tip shape is defined using dry etching techniques on the frontside. Focusing gratings focus the light in a 1 micron diameter size spot 20 microns away from the shank for an unprecedent spatial control of light. Add –drop ring resonators have been fabricated in a test chip: these can select different wavelengths and output them in different spots of the shank through the focusing gratings. Add – drop ring resonators will be added to the probes. In order to input light into the waveguide a fiber with an imprinted Fresnel lens *[4]* is alligned to the waveguide thanks to a microstepper motor stage (Fig. 3). The fiber is then glued to the PCB and detached from the alignment stage. Optical characterizations of these probes will be presented more in detail.

Conclusions - Electrical and optical probes are fabricated on the same substrate and using same etching techniques, showing the feasibility of integrating, with a high density, arbitrarily designed optical and electronic components on the same shank for advancing neuroscience experiments combining simultaneously electrical recordings and optical stimulation.

[1]: Zoltan Feteke Recent advances in silicon-based neural microelectrodes and microsystems: a review, Elsevier, 03-2015
[2]: Gustavo Rios, Evgueniy V. Lubenov, Derrick Chi, Michael L. Roukes and Athanassios G. Siapas, Nanofabricated Neural Probes for Dense 3-D recordings of Brain Activty, Nano Lett. 2016, 16, 6857−6862
[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]: A. Koshelev et Al., High refractive index Fresnel lens on a fiber fabricated by nanoimprint lithography for immersion applications, Vol. 41, No. 15 / August 1 2016 / Optics Letters.

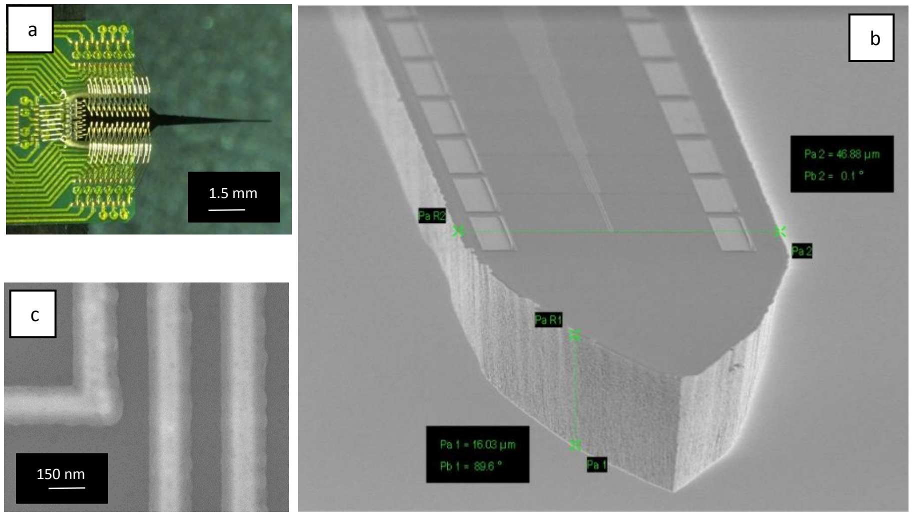

Fig. 1: (a) Optical microscope image of a probe wire bonded on its PCB. (b) SEM image of an electrical probe shank. The shank is 45 um wide, 15 to 20 um thick and 1 mm long. Small shank dimensions mean a lower damage to the brain tissue during the shank's insertion. (c) SEM image of the interconnections. Interconnections on the shank are 120 nm wide and covered by a 50 nm thick passivation layer.

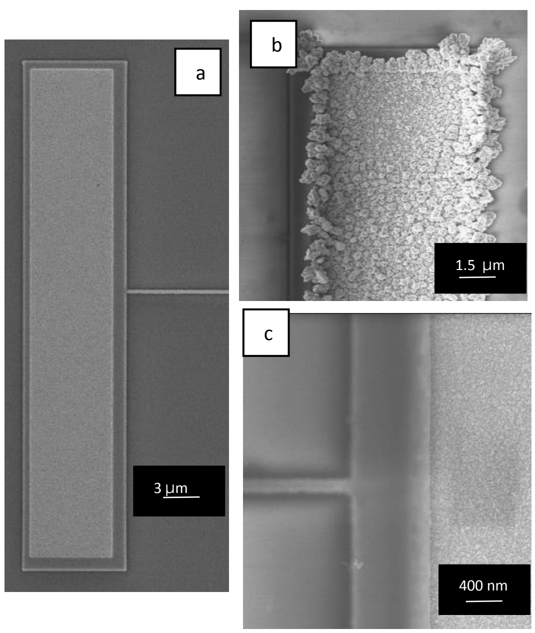

Fig. 1: (a) SEM image of an electrical recording pad (5 X 12 µm) after the probe release from its wafer. Pads are then electroplated with high current (- 3 µA) to obtain big gold grains for rough surfaces (b) or with low current (- 0.1 µA) to obtain smoother surfaces.

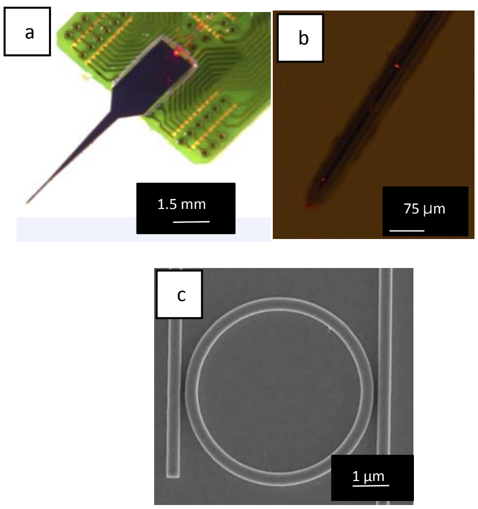

Fig. 5. (a): probe with waveguide and two focusing gratings on shank has been glued on PCB and a fiber is aligned. (b): final result after the holder has been detached from the microstepper motor stage: the laser is turned on and it is possible to appreciate the outputs on the shank. (c): ring resonator fabricated on a test chip.