Photodiode Devices for Stimulation, Electrolysis, and Bubble Production

CNF Project Number: 900-00

Principal Investigator(s): Paul L. McEuen[1,2]

User(s): Samantha L. Norris[1], Michael F. Reynolds[1], Alejandro J. Cortese[1], Yanxin Ji[1]

Affiliation(s): 1. Laboratory of Atomic and Solid State Physics, Cornell University, Ithaca NY, USA; 2. Kavli Institute at Cornell for Nanoscale Science, Cornell University, Ithaca NY, USA

Primary Source(s) of Research Funding: Cornell Center for Materials Research with funding from the NSF MRSEC program (DMR-1719875), Air Force Office of Scientific Research (AFSOR) multidisciplinary research program of the university research initiative Grant FA2386-13-1-4118

Contact: plm23@cornell.edu, sn588@cornell.edu, mfr74@cornell.edu, ajc383@cornell.edu, yj323@cornell.edu

Primary CNF Tools Used: Oxford Cobra ICP etcher, ABM contact aligner, Oxford 100 etcher, Xactix XeF2 etcher, AJA sputter deposition Tool, Oxford PECVD

Abstract:

We present photodiode devices that can be fabricated and released from the substrate in massive parallel using traditional photolithographic techniques. In this report, we discuss fabrication and characterization of these devices, and show some proof of concept measurements for applications in neural stimulation, as well as electrophoretic motion and gas bubble production based on electrolysis.

Summary of Research:

The ability to locally produce voltages and currents with a microscale device that is optically powered lends itself well to a variety of applications. For instance, a cell-scale device would be minimally invasive when inserted into neural tissue and could electrically stimulate surrounding neurons. In addition, these devices can perform electrolysis of the surrounding water, locally changing the pH near the electrodes. Finally, during electrolysis the creation of oxygen and hydrogen gas at the electrodes causes bubble formation, the flow of which can be controlled by the geometry of the device itself.

The entire process utilizes silicon-on-insulator substrates and traditional photolithographic techniques, which enables the production of these devices and their release from the substrate to be performed in massive parallel. To create the silicon photodiode devices, we begin by selectively doping the top of the device layer with phosphosilicate glass to create a vertical PN junction. We then electrically isolate the photodiodes by dry etching to the underlying oxide layer in the Oxford Cobra inductively coupled plasma (ICP) etcher and connect them in series to apply voltages to two metal electrodes on either end of the device. The metal electrodes and interconnects are platinum with a titanium adhesion layer deposited in the AJA sputter deposition tool. We encapsulate the photodiodes with silicon dioxide with the Oxford plasma enhanced chemical vapor deposition tool, leaving the metal electrodes protruding. Finally, we release the devices into solution using a combination of dry and wet etches.

In the presence of incident light, a voltage proportional to the number of photovoltaics wired in series is applied between the electrodes. The current flowing through the device is proportional to the incident light intensity, allowing the electrical characteristics of the device to be tuned *in situ*. The current and voltage characteristics for a 100 µm, seven-photodiode device are shown in Figure 1. Such a device produces ~ 100 µA of current and ~ 4V. These values correspond to those typically used for microstimulation of neurons [1]. We are currently working on inserting these devices onto flight steering muscles in Drosophila melanogaster for in-flight stimulation.

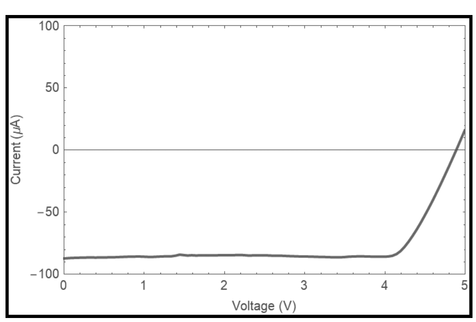

Figure 1: Current vs. bias voltage for a 100 µm, 7-PV photodiode device under 100 nW/µm², 532 nm laser illumination.

When in solution, these devices perform electrolysis of the surrounding water, locally increasing or decreasing the pH near the anode and cathode, respectively. Figure 2 shows a local pH change imaged by adding a colorimetric pH indicator dye, phenol red. These devices could be used as optically powered voltage sources for local electrochemistry or electrophoretic pumps in microfluidic environments and other enclosed geometries.

During electrolysis, the electrodes also drive the conversion of water to hydrogen and oxygen gas at the cathode and anode, respectively. The size and flow of these bubbles can be tuned by changing the geometry of the electrodes. Inspired by previous works on bubble rockets [2], we fabricated devices with a hollow cylinder-like electrode geometry that is tapered to allow bubbles to be preferentially ejected in one direction. Future work includes tuning device geometry to cause self-propulsion by bubble ejection and using bubble production in an enclosed space to cause devices to be neutrally buoyant.

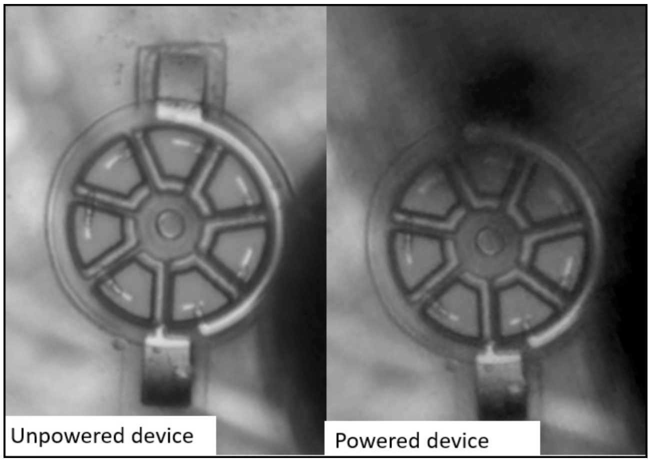

Figure 2: Unpowered and powered device in phenol red pH indicator dye. A darker color is indicative of a higher pH near the anode of the device.

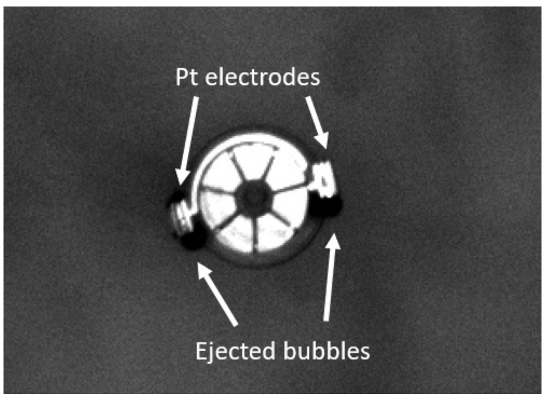

Figure 3: A typical photodiode device with tapered platinum electrodes for bubble production.

References:

[1] Ramasubbu, R. (2018). Dosing of Electrical Parameters in Deep Brain Stimulation (DBS) for Intractable Depression: A Review of Clinical Studies. Frontiers in Psychiatry.

[2] Gallino, G., Gallaire, F., Lauga, E., and Michelin, S. (2018). Physics of Bubble-Propelled Microrockets. Advanced Functional Materials.