Microscopic Optically Powered Bubble Rockets

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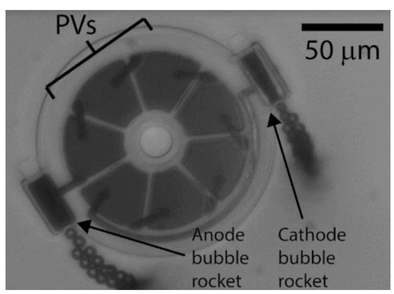
Primary CNF Tools Used: Heidelberg DWL2000 mask writer, ABM contact aligner, Oxford 81/82/100/Cobra etchers, Xactix XeF_2 vapor etcher, AJA sputter deposition tool, Oxford PECVD, Arradiance ALD

Abstract:

We present artificial microswimmer devices that can be released from the substrate and propel themselves in fluid using bubble production and ejection. Unlike many other bubble-propelled microswimmers, ours operate in a range of fluids, including deionized water. These devices 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 discuss initial results.

Summary of Research:



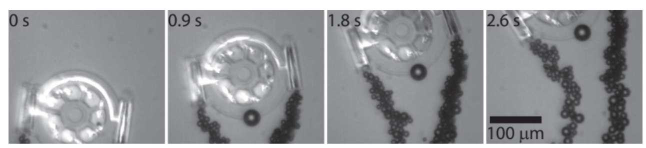


Figure 1, left: A bubble rocket in deionized water producing hydrogen at the cathode (left) and oxygen at the anode (right). Figure 2, above: A time lapse of a bubble rocket device swimming at an air-water interface, powered by a mercury lamp. The torque on the device is due to the inequality of hydrogen and oxygen production.

The ability to wirelessly power an artificial microswimmer lends itself well to a variety of applications, including *in vivo* cargo delivery [1]. Our technique for device fabrication and release from the substrate is fully scalable, allowing hundreds of thousands of devices to be studied simultaneously. In addition, the devices can be integrated with CMOS circuitry from commercial foundries, laying the foundation for additional complexity in the future.

For bubble propulsion, we create devices consisting of silicon photodiodes that provide enough voltage to perform electrolysis at two protruding electrodes, producing hydrogen and oxygen gas at the cathode and anode respectively (Figure 1). Inspired by previous works on bubble rockets [2], the electrodes are tapered to eject the produced bubbles preferentially in one direction, causing the device to be propelled forward. Under an illumination intensity of about 100 nW/μm^2 at 532 nm, a 100 μm diameter device consisting of seven photodiodes can produce about 20 μA and 4.5V. A device using bubble ejection for self-propulsion in deionized water is depicted in Figure 2.

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 buried oxide layer in the Oxford Cobra inductively coupled plasma (ICP) etcher. At this point, we also define the shape of our tapered electrodes in the silicon.

We then connect the photodiodes in series to each other and the electrodes, also conformally coating the silicon defining the electrodes in metal at this step. 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 using the Oxford plasma enhanced chemical vapor deposition tool, leaving the metal electrodes protruding.

Finally, we connect aluminum supports to the devices and undercut the silicon underneath them with the Xactix XeF_2 etcher — this also etches the silicon of the rockets, leaving a hollow tapered oxide cylinder with a metal undercoating. Our devices can then be released from the substrate after immersion in any aluminum etchant.

Because the operation of these devices isn't dependent on a fuel source on the electrodes or in the solution, our bubble rockets operate in a range of solutions, even deionized water. The fabrication is entirely CMOS-compatible, allowing for the future integration with more complex circuitry to enable steering and phototaxis.

References:

[1] Gao, W., Dong, R., Thamphiwatana, S., Li, J., Gao, W., Zhang, L., and Wang, J. (2015). Artificial Micromotors in the Mouse's Stomach: A Step toward *in vivo* use of Synthetic Motors. ACS Nano.

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