Electrically Controllable Micro-Machines

CNF Project Number: 2416-16

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Primary Source(s) of Research Funding: National Science Foundation, Contract DMR-1719875; DMR-1435829 Army Research Office, Contract W911NF-18-1-0032

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Primary CNF Tools Used: Oxford ALD FlexAL, Arradiance ALD Gemstar-6, Oxford 81/100 etchers, ABM contact aligner, CVC SC4500 odd-hour, AJA sputter deposition, AJA ion mill, Oxford Cobra ICP etcher, Heidelberg DWL2000

Abstract:

Electromechanically adaptive materials are poised to revolutionize microscopic robots, robotic materials, and bio-implantable devices. Previously, we have demonstrated that the electrochemical micro-actuators made by atomically thin layers of metals and dielectrics could bend in response to a low voltage of ~ 1V. Here, we utilized this new type of micro-actuators to develop complex microstructures and micromachines, such as auxetic mechanical metamaterials, neural probes, and artificial cilia.

MECHANICAL DEVICES

Summary of Research:

Nanofabrication of electromechanically active materials could create micromachines with unparalleled properties and functionalities [1]. The core of these devices consists of a nanometer-thin platinum layer as an electrochemically active material capped on one side by titanium as an inert layer. To demonstrate their broad applications, our team has developed three types of such micro-devices: auxetic mechanical metamaterials, neural probes, and artificial cilia.

Our team first developed micro-sized auxetic mechanical metamaterials by using origami design principles [2]. Auxetic mechanical metamaterials comprised of rigid panels that can locally splay, have the ability to yield reconfigurable curved surfaces and generate different locomotion gaits for robotics applications. We show that such electrically actuated auxetic metamaterials can be utilized to design micro-scale robots. As in their macroscopic counterparts, the expansions and contractions in our devices are achieved by splaying neighboring panels. To achieve this splay actuation we developed an origami hinge based on a single mountain and two valley folds. The actuation of the hinges is controlled by applying voltage to a nm thin surface electrochemical actuator. The local expansions and contractions alter the local Gaussian curvature of the metamaterial sheet allowing it to reconfigure into a continuous set of three-dimensional shapes. We modeled the target shapes using a reversed design approach in which the shapes are iterated towards target shapes by selecting optimal actuations of the splay hinges. We then show experimentally we are able to generate 2D and 3D shapes by actuating the hinges. Based on these proof of principle results, we are working towards manufacturing untethered metamaterial-based micro-scale robots with integrated photovoltaics and timing circuits that control the sequence of hinge actuations and resulting global shapes and locomotion gaits.

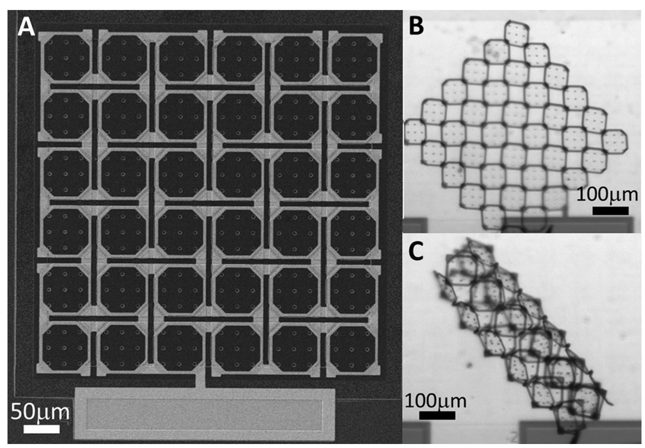

Figure 1: Electrically programmable auxetic mechanical metamaterials. (A) SEM image of a mechanical metamaterial sheet. (B,C) The sheet could deform into two-dimensional and three-dimensional shapes.

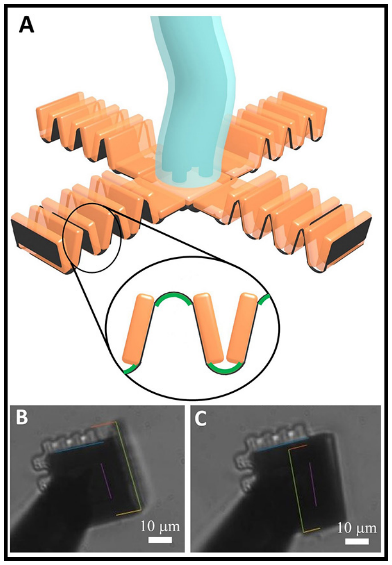

Figure 2: Robotic neural probe. (A) Schematic of an origami-based deployable neural probe. (B,C) Optical images of the bendable probe actuated from -88° to 134° when varying the voltage from 0.6V to -1.2V in phosphate buffer solution.

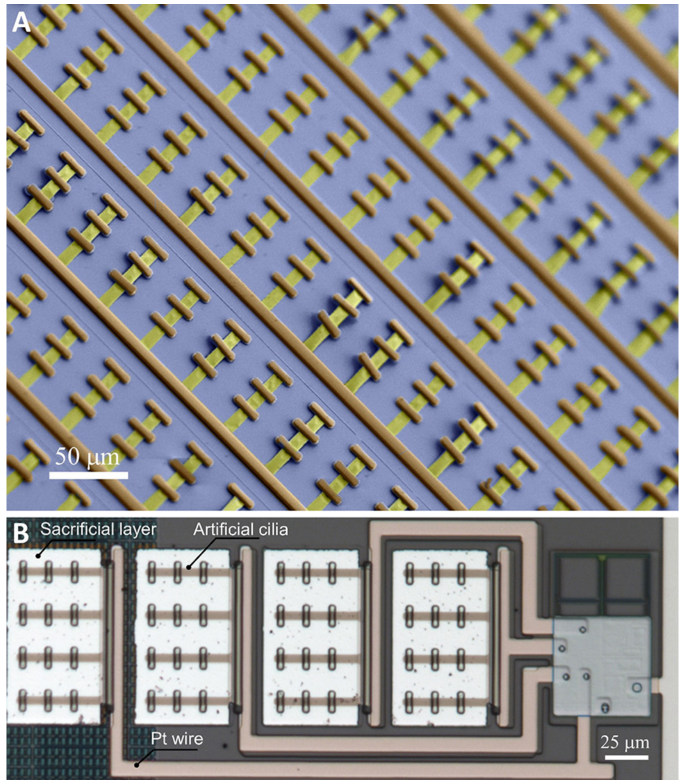

Figure 3: Electrically actuated artificial cilia. (A) SEM image of artificial cilia arrays. (B) Optical image of artificial cilia integrated with control circuit.

Our second project is to use the micro-actuator and origami principle to design robotic neural probes. The ability to actuate the non-toxic materials in the brain paves the way for neural sensing probes that do not require an invasive borehole the size of the area to be sensed, through the cranium and pia-mater. Although the platinum-based micro-actuator we developed previously works perfectly in PBS solution, the fact that the oxidization reaction that drives the actuation of platinum is not scalable with the thickness of the platinum, meaning only the same amount of strain energy can be held in a platinum beam regardless of the thickness (implying a smaller curvature). This limitation presents a challenge with the group's current actuation design if used for neural probes. Since the brain, or brain-like gel, requires much more force to move through compared to the aqueous solution currently used by the group, an actuator needs to store enough energy to effectively displace a gel, while still being able to actuate over a wide range of angles. For this reason, we explored bulk electrochemical micro-actuators that utilize hydrogen adsorption/desorption effect to generate the strain in the thin film. In this system, hydrogen diffuses into the bulk of actuator, creating a bulk stress in the composite that scales with the thickness of the actuator. This new type of micro-actuator has much larger output force than the preview platinum micro-actuator while keeping the bending radius as small as the platinum counterpart.

Last, our team designed microfluidic devices that comprise arrays of such micro-actuators [3]. Microfluidic patterns are crucial in aspects from regulating cerebrospinal fluid in brain, guiding chemical reactions to manipulating particles. The traditional microfluidic devices use micro-channels and external pumps to guide the flow motion. The flow direction is determined by the micro-valves and cannot be changed once fabricated. Here, a new type of integrated microfluidic manipulation system which is built on the electrically actuated artificial cilia is proposed to achieve reprogrammable flow motions. The electrical chemical platinum actuator which has low voltage, low power and fast response time is used to fabricate the artificial cilia. The artificial cilia are compatible with CMOS fabrication and packaging technology and can be easily manipulated by computer software and micro-processor through tethered or untethered control. It gives a new platform to make powerful microfluidic devices and study the programmable motion of micro robotics.

References:

[1] Liu, Q., Wang, W., Reynolds, M.F., Cao, M.C., Miskin, M.Z., Arias, T.A., Muller, D.A., McEuen, P.L. and Cohen, I., 2021. Micrometer-sized electrically programmable shape-memory actuators for low-power microrobotics. Science Robotics, 6(52), 2020.

[2] Liu, Q., Wang, W., Sinhmar, H., Cortese, A., Griniasty, I., Reynolds, M., Taghavi, M., Apsel, A., Kress-Gazit, H., McEuen, P. and Cohen, I., Electrically Programmable Micro-scale Morphing Robots Based on Mechanical Metamaterials. Bulletin of the APS 2021.

[3] Wang, W., Liu, Q., Reynolds, M., Miskin, M., McEuen, P. and Cohen, I., 2021. Electrically actuated artificial cilia for microfluidic applications. Bulletin of the American Physical Society, 2021.