Controlling the Pre-Curvature of Surface Electrochemical Actuators for Microscopic Robots

2021 CNF REU Intern: Zhangqi Zheng

Intern Affiliation: Engineering Physics (intended), Cornell University

CNF REU Principal Investigator: Paul L. McEuen, Department of Physics, Cornell University

CNF REU Mentors: Samantha Norris, Department of Physics, Cornell University; Michael F. Reynolds, Department of Physics, Cornell University

Primary Source of Research Funding: 2021 Cornell NanoScale Science & Technology Facility Research Experiences for Undergraduates (CNF REU) Program via National Science Foundation under Grant No. NNCI-2025233

Contact: zz365@cornell.edu, plm23@cornell.edu, sn588@cornell.edu, mfr74@cornell.edu

Primary CNF Tools Used: ABM contact aligner, Arradiance ALD Gemstar-6, AJA sputter deposition (1&2), AJA ion mill, Heidelberg mask writer - DWL2000, Oxford 80 etchers, Xactic xenon difluoride etcher

Abstract:

Smart microscopic robots, capable of performing complicated tasks while at a few hundred microns in size, have revolutionary potential in many fields. Recent research in our group has developed a promising approach towards producing such smart microscopic robots [1]. One important component of this kind of robot is the Surface Electrochemical Actuators (SEAs) [1,2], which function as the legs of the robots. With the current recipe, the SEAs have an innate pre-curvature, causing the legs to bend underneath the bodies of the robots right after release, while ideally, we would like to control the angle of this bending. In this research, we were able to change the pre-curvatures by varying the deposition pressure of titanium during the fabrication of the SEAs, showing that we can tune the pre-curvatures of the legs of smart microscopic robots through the fabrication process.

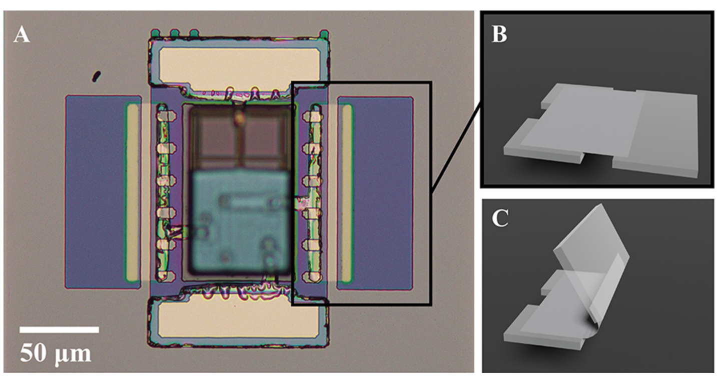
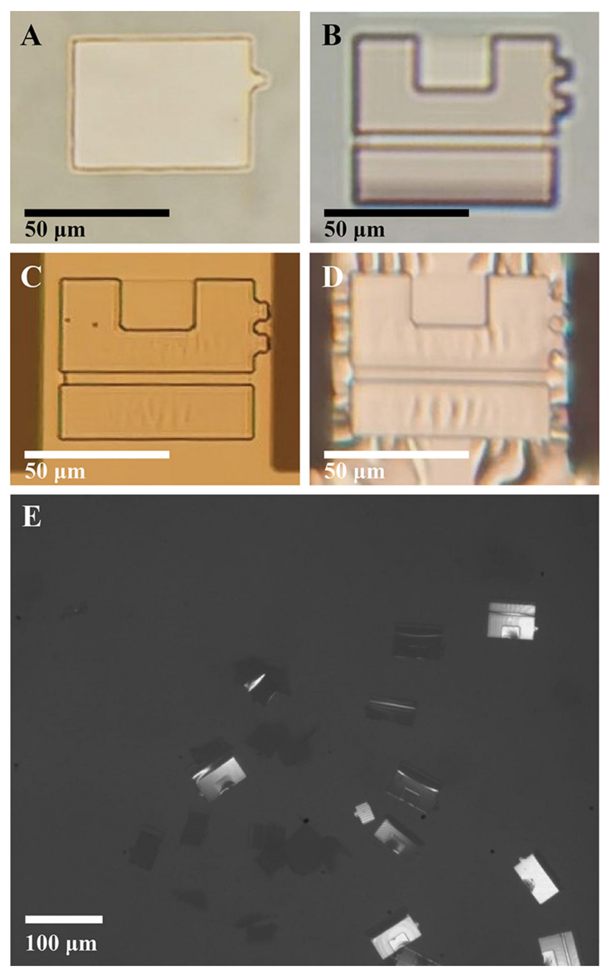


Figure 1, above: (A) Image of a smart microscopic robot before release. (B) 3D illustration of a leg of the microscopic robot before release. (C) 3D illustration of a leg of the microscopic robot after release. Figure 2, right: Fabrication process (A) metal layer, (B) polymer panel, (C) aluminum release layer, (D) after XeF_2 etching, and (E) after release.



Summary of Research:

These microscopic robots developed by our group are the first of their kind, integrated with on-board circuitry that controls the motions of the robot, photovoltaics that provide power for the robot, and legs that make the robots move. Figure 1A shows an image of one of these robots when it is fully fabricated, prior to release (Reynolds, M.F. et al. Unpublished). Inside the box on the right side of the image is one of its legs, which is also shown with a 3D illustration in Figure 1B. The key component of such leg that provides its functionality is the Surface Electrochemical Actuator (SEA). Made of a 7 nm thick platinum (Pt) thin film capped on one side with about 3 nm thick of titanium (Ti), the SEAs actuate under a voltage supply [1]. Before any actuation, however, the SEAs naturally bend towards the Pt side of the film when they are released, as shown in Figure 1C. This pre-curvature is caused by the stress of the metal films, which is largely influenced by the deposition pressure of the Ti. We use the AJA sputter deposition #2 at the CNF for depositing the Ti. Previous data collected by the CNF staff show that the pre-stress of an over 200 nm thick Ti film deposited at 3 mTorr is -178 MPa, while that of the same thickness deposited at 7 mTorr is 28 MPa. Through this research, we investigated how this difference in pre-stress due to different Ti deposition pressure causes variation in the pre-curvature of the SEAs. By fabricating SEAs with various Ti deposition pressure and measuring and comparing the pre-curvature of them, we confirmed that we can tune the pre-curvature of SEAs by changing Ti deposition pressure.

Figure 2 demonstrates the fabrication process for the leg hinges that are used for testing the pre-curvature of the SEAs. We start by depositing the Pt and Ti metal films and etching them to a rectangular shape (Figure 2A). For the purpose of this research, we deposited Ti at three different deposition pressures — 3 mTorr, 5 mTorr, and 7 mTorr — on three different silicon (Si) chips. After depositing the metal film, we fabricate the polymer panels that keeps the rest of the SEAs film in these leg hinges straight, ensuring that only the exposed SEAs film in the 3 μm gap between the panels bend when actuated (Figure 2B). We then sputter a layer of aluminum covering the hinges (Figure 2C). After we etch the Si substrate underneath, the hinges are tethered only by the aluminum (Al) on top of them (Figure 2D). For the last step we release the hinges by putting the chips upside down in Al etchant, and the chips fell off of the substrates to the bottom of the Petri® dish (Figure 2E).

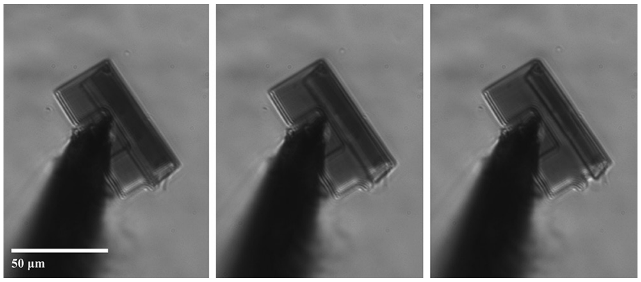


Figure 3: Optical images of a leg hinge during actuation.

We then tested the hinges for actuation by touching down to the SEAs with a Pt/Ir probe and applying a voltage through the probe. We observed actuation of hinges with Ti deposited at all three deposition pressures when we applied a triangular wave with 1.2 V amplitude (Figure 3), showing that the hinges can function as expected with the different deposition pressures.

Figure 4 shows a plot of the pre-curvatures measured from the leg hinges against the Ti deposition pressure of the hinges. Above each Ti deposition pressure is an image of a hinge fabricated with the deposition pressure. The average pre-curvature for each deposition pressure has a clear trend

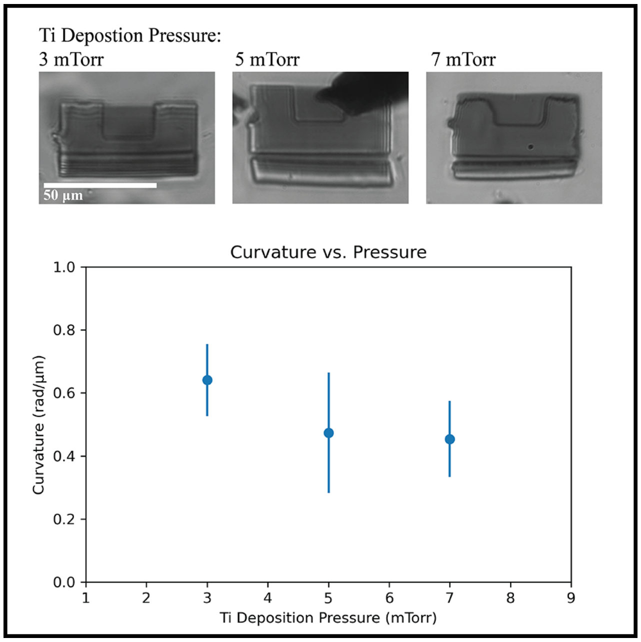


Figure 4: Data of pre-curvatures of SEAs hinges at different Ti deposition pressures.

where lower deposition pressure produces a larger pre-curvature, which matches the behavior of the pre-stresses measured at 3 mTorr and 7 mTorr. This indicates that we can tune the pre-curvature of the SEAs by changing Ti deposition pressures, and that the hinges fabricated with Ti deposited at all three deposition pressures function as expected.

Conclusions and Future Steps:

Overall, the tunability of the pre-curvature of the SEAs via changing Ti deposition pressure demonstrated in this research allows us to have better control of the initial leg shapes for smart microscopic robots. Instead of having a fixed arbitrary bending after release, this tunability allows us to fabricate future generations of smart microscopic robots with their legs bent at the angle we prefer upon release.

Acknowledgements:

I would like to acknowledge the support of the National Science Foundation, National Nanotechnology Coordinated Infrastructure, and Cornell NanoScale Facility Research Experiences for Undergraduates (CNF REU) Program (NSF grant no. NNCI-2025233). I give special thanks to my PI Dr. Paul McEuen, mentors Samantha Norris and Michael F. Reynolds, and the staff at the CNF.

References:

[1] Miskin, M. Z., et al. Electronically integrated, mass-manufactured, microscopic robots. Nature 584, 557-561 (2020).

[2] Liu, Q., et al. Micrometer-sized electrically programmable shape-memory actuators for low-power microrobotics. Science Robotics 6, (2021).