

## From Atomic Origami Towards Cell-Sized Robotics

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### Abstract

We envision the next generation of nanotechnology as machines that are active at time and length scales comparable to biological microorganisms. These machines will be able to change shape in fractions of a second in response to environmental cues, carry electronics, be fabricated en masse using standard semiconductor processing techniques, and cost less than a cent per machine. The key breakthrough behind this future? Origami with atomically thin paper.

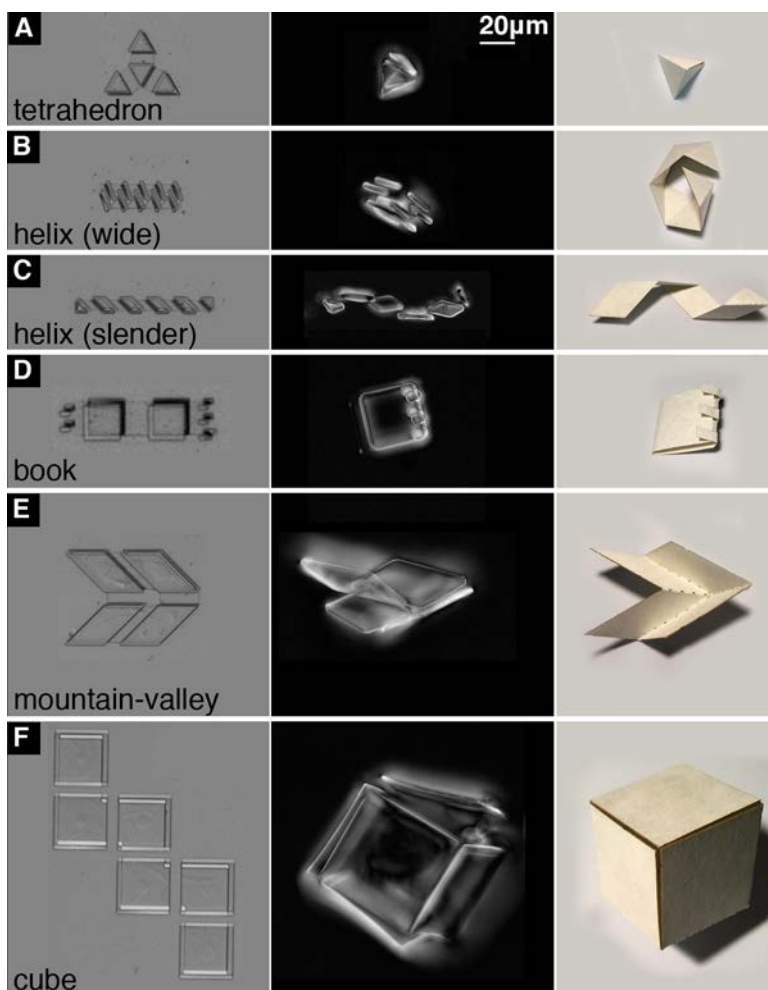


Figure 1: Structures made using graphene Origami

Our team is shrinking do down origami-robotics to become the fundamental platform for nano-robotics by folding atom's thick paper. In origami robotics, actuators, patterned on a sheet, are used to fold complex, reconfigurable 3D structures. This platform is prime for miniaturization because fabrication can be done in plane with tools like photolithography, designs are scale invariant, and flat panels linked by the folds provide a natural place to integrate electronics.

The most basic challenge to miniaturizing origami robots is in actuator design. A single actuator must be capable of bending to micron radii of curvature, produce force outputs large enough to lift embedded electronics, and maintain electrical conductivity across folds while bending. In this talk, we show how

actuation technologies based on atomic membranes, like graphene, resolve these problems because they can:

- bend to micron radii of curvature using strains that are 100x smaller than the fracture strain for inorganic hard materials, thus maintaining electrical functionality across the actuator.
- lift the weight equivalent of a 500nm thick silicon chip, enabling embedded electronics.
- create folds and origami motifs when restricted by rigid panels that prevent bending
- be fabricated and deployed en masse: 10 million devices fit on a 4 inch silicon wafer.
- change shape from flat to folded in fractions of a second.
- operate using power from embedded photovoltaics.
- be controlled by standard CMOS electronics.

This talk is about the steps that we are taking in moving towards true robotic systems at the cellular scale by integrating nanoscale Origami actuators with electronics. We show how to design and build ultra high efficiency actuators for self-folding machines that are powered by voltage. These devices can be powered and controlled using standard CMOS electronic components like photovoltaics and MOSFETS. As a first step, we will discuss basic prototypes that use on-board photovoltaics to power origami actuators. The resulting device can then change shape from flat to folded when external power is supplied through light fields.

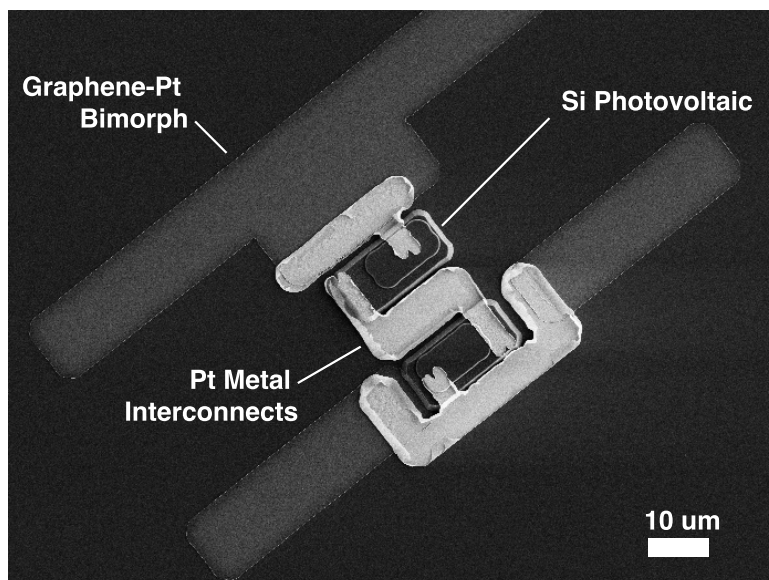


Figure 2: A first prototype integrating silicon based photovoltaic with atomic origami actuators