Three Dimensional Biomimetic Artificial Muscles for Micro-Robotic Applications

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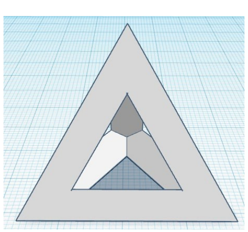
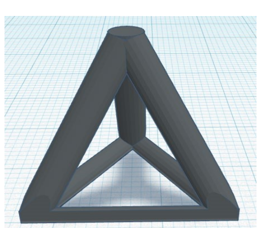
The proposed piezoelectric model may serve as an artificial biomimetic muscle for application in micro-robotic systems. The model is designed as a building block of a larger structure. The final actuator is to be composed solely of a ceramic material Zinc Oxide (ZnO). This is a brittle material which when applied to specific geometric dimensions and scaled to a micro scale will give the material new properties. When a piezoelectric material such as ZnO is acted upon by an electric field the reaction of deformation is proportional to the applied voltage and its direction. This is known as an inverse piezoelectric effect. The scale of the model and its dimensions will give the model new physical properties that of strength and resilience, to produce large forces from small voltages. The proposed application is for small drones that would mimic the flight pattern of certain insects such as a dragonfly (1).

Piezoelectric material properties have been known starting in the late 18^{th} century and were first used in sonar during the world war. Today this material is used in the medical industry as ultrasound to visualize internal structures. Another application is in microscope stages. This material is a great replacement for traditional actuators in micro robotics because motors are heavy and bulky and are difficult to construct on small scales. Some have used the piezoelectric actuator to mimic the flight pattern of a dragonfly but the energy consumed by the actuator is far greater than that which can be provided onboard. But unfortunately the model drone must have tethers to operate. The idea is to use the same piezo-actuator material constructed to give the material lower density and power consumption in order to have enough power from the onboard energy source.

The model was inspired by triangles and tetrahedrons due to their structural resilience. It seemed as an obvious choice since most models can be modeled using a variety of triangular shapes as for example in the COMSOL Multiphysics simulation. The model itself consists of three micro tubes arranged in a tripod manner. This model is essentially a building block whose design can be used to design a structure as large as needed for the task. Adding these models vertically will increase the displacement generated and adding them horizontally will increase the force generated.

A.  B.  C. 

D. 

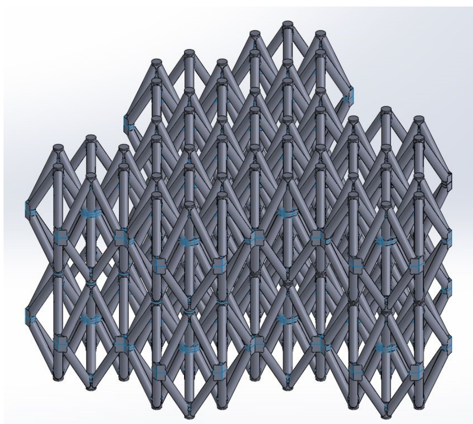
A. This is the original idea, which led to the development of the current model. Due to the model's tetrahedral form it will have strong structural properties. It will also enable the model to become a modular building block to create larger structures.

B. This model represents the original model inspired by the tetrahedral geometry to be a hierarchical building block for a larger structure (Image E).

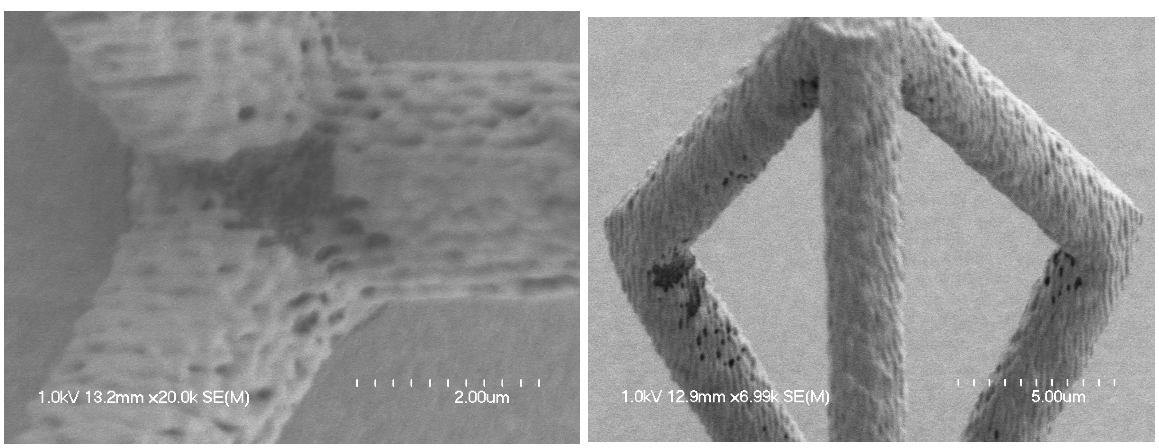
C. The previous model was modified to give the model less mass and more displacement. For this reason the horizontal components were removed.

D. Once the model was coated it was shown that sharp angles in the model cause poor deposition in the sharp groves. To improve this imperfection, curved surfaces were added to ensure more reliable Zinc Oxide deposition.

E.



F.



This is the model version in the image C that was run through the Atomic Layer Deposition (ALD). The Zinc Oxide in this image was not deposited evenly, even though it should have according to the ALD process. Image E demonstrates the issue that was addressed by adding the curvatures to the model. So the next generation model in image D should resolve this issue. It is also important to mention that the resolution will need to be much higher in the next trials to ensure a smother surface. The model currently stands at about twenty micrometers tall and twenty-two micrometers wide at the base. The micro tubes are to be three micrometers in diameter and are to be thirty nanometers in thickness. The model is essentially a hollow structure, which has very low density and therefore low power consumption.

The model is thoroughly tested in COMSOL Multiphysics to ensure that the model behaves as intended. The results show that the applied voltage is linearly proportional to the generated force and displacement of the model. For the model to produce highest efficiency it needs to be at its' maximum energy density (1). The model needs to be composed of Zinc oxide, arranged in a Wurtzite lattice configuration. The other form it can have is the Zincblende Cuboidal. There is still research to be done to determine the factors affecting the lattice orientation upon deposition.

The model is initially printed using a two-photon lithography polymerization system, also known as Nanoscribe. Using the IP-Dip photoresist on a glass substrate the model is printed in a variety of positions and combinations to test for structural stability. Note that the print resolution needs to be as smooth as possible since the result will be greatly affected. The next step requires the deposition of the Zinc Oxide piezoelectric material onto the model using Atomic Layer Deposition (ALD). This machine deposits a layer of the material one atomic layer at a time and is best suited for the task due to the model's design being three-dimensional. Once the model is successfully printed and deposited, the interior polymer needs to be removed to make the model hollow. This is done using the Focused Ion Beam (FIB) machine to expose the inside polymer. The O_2 Plasma Reactive Ion Etching (RIE) will ensure the polymer is removed, leaving only the ZnO structure. The X-Ray Diffractometer (XRD) will analyze the structure to ensure that only the desired ZnO material remains, and that it has the Wurtzite lattice configuration. The resulting structure will be subjected to a load in a Nanoindenter to find the model's fracture point and to address it accordingly. Once that is resolved, the model will be actuated via electrodes and will be integrated into the final device with specific mechanical amplifiers. Many refinements will need to done to ensure the desired model outcome.

Piezoelectric materials are still under intense research to find how these various materials can be deposited to better suit the actuator. The development of smaller robotic devices requires smaller and more efficient actuators. As the industry develops, the demand and the uses of these actuators will become more apparent.

Sources:

(1) M. Karpelson, R. Wood, Driving high voltage piezoelectric actuators in microrobotic applications, Elsevier, 2012, School of Engineering and Applied Sciences, Harvard University, United States.

(2)DARPA, Short Range Independent Microrobotic Platforms, Microsystems Technology Office, 2018.

(3) Nelson, T. B. "Building Medical ‚sized", TedxTallks, 28 November, 2012