Incorporating 3-D Printed Battery Materials for Energy Storage

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Introduction

The drive for renewable resources is at an all time high, due to rising levels of greenhouse gas emissions causing climate change. There have been developments in harvesting renewable energy sources such as solar panels and windmills. These are promising alternatives to fossil fuels; however, they provide power intermittently. We must develop advanced energy storage technologies to compensate for times when wind and solar power does not meet grid-scale demands. Flow batteries which consist of two porous electrodes and a scalable electrolyte tank, are an emerging technology for large scale energy sources. An important scientific and engineering opportunity in flow battery design is studying the relationship between the porous electrode geometry and battery efficiency. To better understand this relationship, we print three-dimensional battery electrodes in the Lewis Lab, at Harvard University to incorporate into flow battery systems. We anticipate that the 3-D structures will improve energy storage and battery performance.

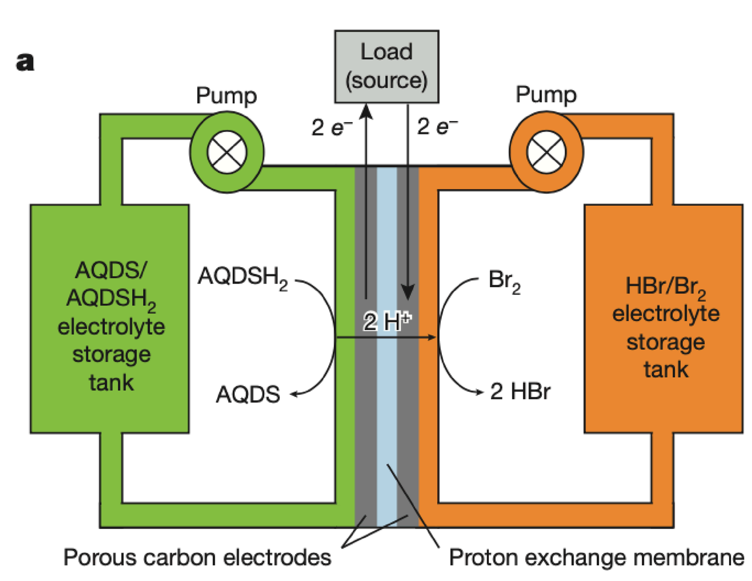

Fig. 1: Flow battery diagram. (Brian Huskinson, *Nature* **2014**)

Methods

Electrode Fabrication

The materials required to print our battery electrode lattices are a graphene-based ink, which we make in lab, a glass substrate to print onto, and our 3-D printer setup, which includes a barrel filled with ink, a 30-micron diameter glass nozzle, an air supply to extrude ink, an extruder that moves in the X, Y, and Z directions and the code to control the extruder. Then we use a method of 3-D printing known as Direct Ink Writing. Direct ink writing allows us to print intricate three-dimensional shapes, if the ink we use has specific rheological properties. We print in meanders in both the X and Y directions and stack our printings on one another. The alternation of meanders gives us a lattice like shape after 7 total layers. Once we complete the printing process, we carefully remove our electrodes from the glass substrate and place them in a vial filled with milli-Q water to get rid of any air bubbles. Next, we glue several samples of our electrode to another piece of glass, and we place our electrodes in an oven to completely dissolve the solvents used in the printing process. Once our electrodes are dry, we subject them to an oxygen plasma treatment to oxidize the ink. Then we submerge our electrodes in Tin Chloride to sensitize our electrodes. Then our electrodes become activated after we submerge it in palladium chloride. Then we submerge it in a nickel solution for electroless plating, and finally we gold plate our electrodes by applying an open circuit voltage and submerging them in a gold plating solution.

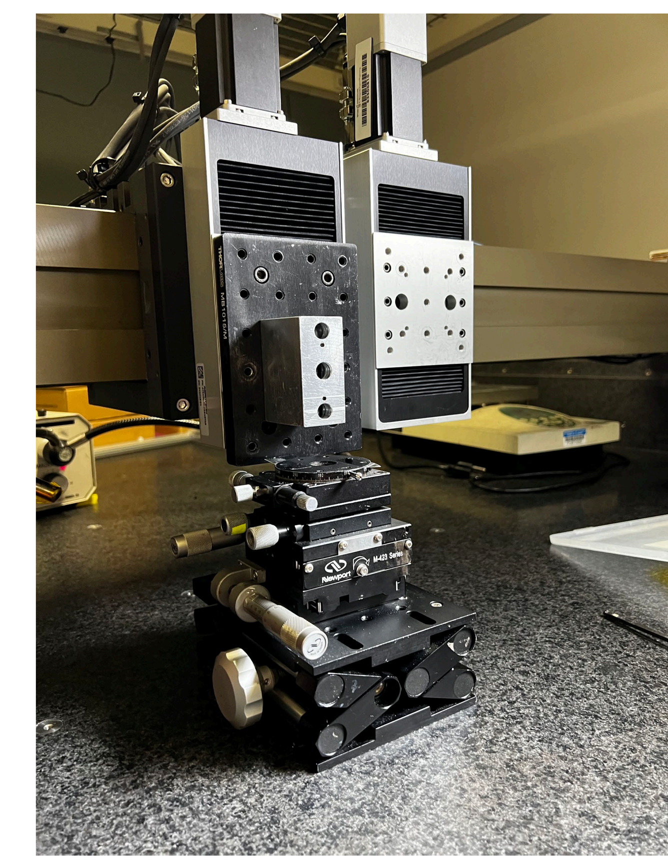

Fig. 2: 3-D Printing Setup at Harvard University

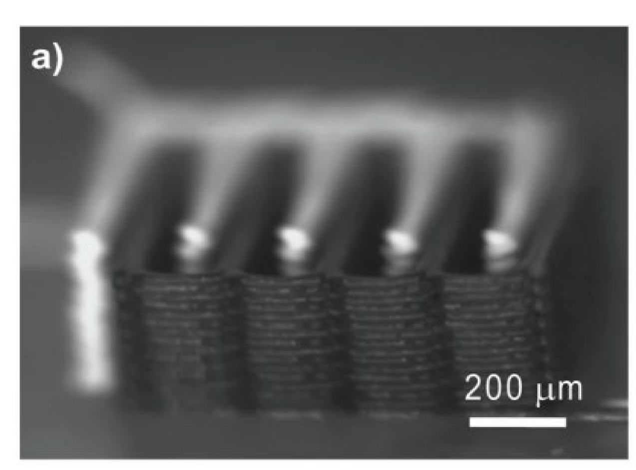

Fig. 3: Electrolyte flow path in an interdigitated electrode. (Ke Sun, *Material Views* **2013**)

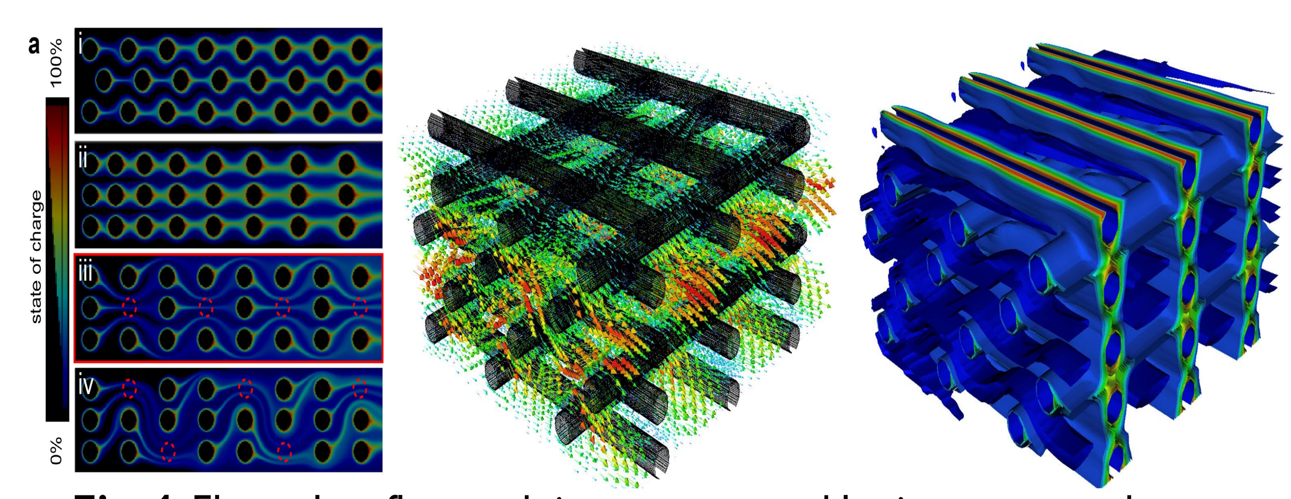

Fig. 4: Electrolyte flow path in our proposed lattice structured electrode. (Simone Dussi, *Physics of Fluids* **2022**)

Results & Discussion

Energy demands are on the rise worldwide. We are consuming massive amounts of coal and petroleum derived products. We rely on fossil fuels for transportation and for supplying energy to our homes. This is causing significant environmental concerns such as rising greenhouse gas emissions. One alternative to fossil fuels is renewable energy sources. An issue with renewable energy is having a consistent source of energy. Renewable energy sources are intermittent, meaning they are not available all the time. We can store the renewable resources using a redox battery system. Redox flow batteries are particularly useful in storing large amount of energy. We can scale the size of the electrolyte tanks on our battery system to store more energy without increasing the size of the electrodes, which could be a promising alternative to storing renewable energy. One issue that may arise when scaling up the redox flow battery system is the distribution of reactants to the electrode. The electrodes need to be porous to increase the surface area, which would allow more interaction with the electrolyte. By implementing a lattice structure, we can increase the amount of surface area contact with the electrolyte to make our battery electrodes more efficient. We can implement a lattice structure to our electrodes by 3-D printing a stack of lattices. The Method for printing is known as Direct Ink Writing. We can also make the surface of our electrode more conductive by applying both a nickel plating and a gold plating.

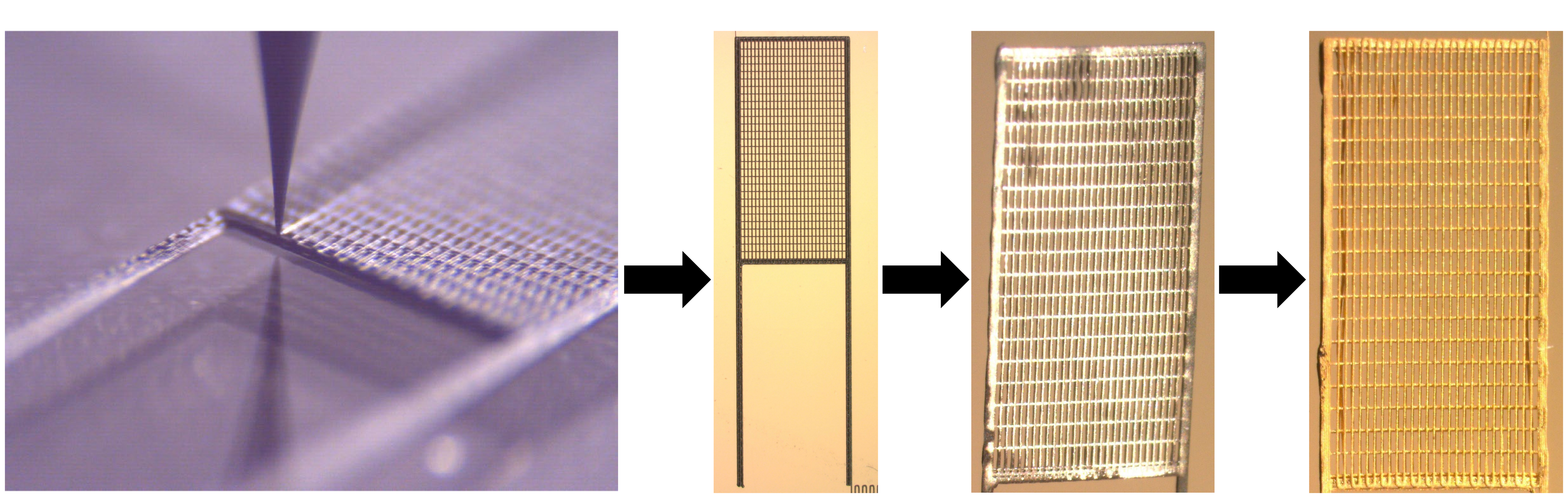

Fig. 5-8: The photos above depict the fabrication process, starting with printing (Left), next is our printed electrode, then our electrode after it has been coated in Nickel, and finally our gold-plated electrode (Right).

Conclusion

- We have successfully learned the 3-D printing technology from Harvard University, and we are in process of transferring that technology to Navajo Technical University.
- Using the technology we learned, we hope to incorporate 3-D printing energy system materials to redox flow batteries.

References

- Lin, Tiras Y. "Topology Optimization of 3D Flow Fields for Flow Batteries" (2022).
- Leung, P. "Recent Developments in Organic Redox Flow Batteries: A Critical Review" (2017).
- Huskinson. Brian "A Metal-free Organic-Inorganic Aqueous Flow Battery (2014).

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