Fractal Electrodes

Patrick Butera

Chemical Engineering, University of Connecticut

NNIN REU Site: ASU NanoFab, Arizona State University, Tempe, AZ
NNIN REU Principal Investigator: Dr. Michael Kozicki, School of Electrical, Computer, and Energy Eng., Arizona State University
NNIN REU Mentor: Ankitha Chandran, School of Electrical, Computer, and Energy Engineering, Arizona State University
Contact: patrick.butera@uconn.edu, michael.kozicki@asu.edu, achand27@asu.edu

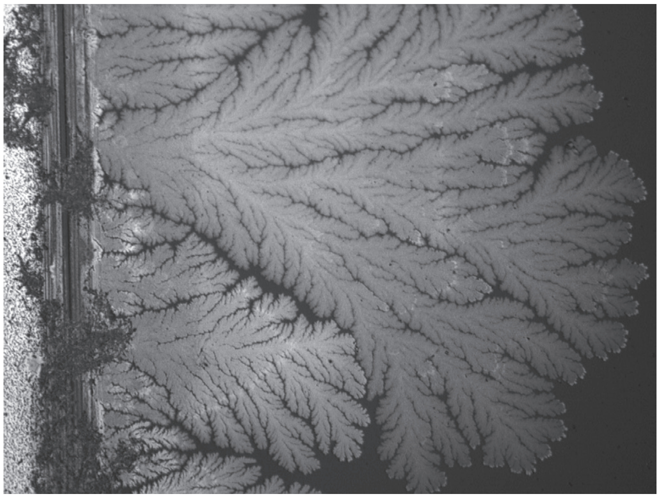

Figure 1: A sample cathode. Dendrites are growing to the left as more silver ions reach the cathode. There are multiple layers of dendrites visible.

Abstract:

Fractal electrodes (dendrites) provide an opportunity to improve many electrical and optical areas including solar cells, sensors, and in the future, retinal replacements. They offer a unique ability to carry either information or charge with minimal resistance, while only covering a small fraction of surface area. These electrodes can be easily made by applying an electric field between an anode and cathode which causes the dendritic metal electrodeposit to form. One key characteristic of the fractal electrodes is the fractal dimension, which is used to describe non-Euclidean geometries. The purpose of this project was to determine the level of control that can be obtained through use of constant current and constant voltage during electrodeposit growth. Thin films of silver were deposited on slides via thermal evaporation. The mask used provided channels between the silver electrodes in which the dendrites could grow. The dendrites, as seen in Figure 1, were then imaged and processed to determine their fractal dimension. It was found that the fractal dimension decreases with an increase in field, in both constant current and voltage trials. The data confirms that a stronger field leads to more one dimensional growth.

Experimental Procedure:

Silver (Ag) deposition was carried out using thermal vapor deposition. The chamber of the Cressington was vacuumed down to 3×10^{-6} mbar. Between 47 and 50 nm of Ag was deposited on the glass slide. Channels to carry out the electrodeposition were created with a mask of Mylar tape. Each channel was probed using an Agilent 4155C semiconductor parameter analyzer. Either constant voltage or constant current were applied across the channel for various amounts of time to produce the dendrites. Once the dendrites were grown, an Axiophot microscope was used to produce the images. Three images were taken for each dendrite. The fractal dimension was calculated in MatLab using a box counting approximation. Results were then averaged for the three images to calculate the fractal dimension for the trial. Experiments at 2 volts and 25 μA were tested from two minutes to ten minutes every minute. For 5 volts, 35 μA, and 50 μA trials, the times tested went from 90 seconds to 240 seconds every 30 seconds. And the higher field trials, 10 volts and 75 μA, were tested from 30 seconds to 60 seconds in ten second intervals.

Results and Conclusions:

As seen in Figure 2, the higher the voltage, the lower the fractal dimension tended to be. Similarly, when the current was held constant, higher currents lead to lower fractal dimensions. For the constant voltage trials, Figure 2, the data was not scattered, with the exception of one outlier. The constant current data was much more varied, as seen in Figure 3.

There are many possible areas of error, especially during the probing. One example is how far the probes were from the channel. This varied from sample to sample. Another potential reason could be the contact of the probe to the deposited silver. If the probe was pressing too hard, it could scrape off the silver, which would increase the resistance. On the other hand, if the probe was not pressed hard enough, then the probe would not be making good contact with the silver. For more exact data, these problems would need to be addressed, but a strong negative trend was found.

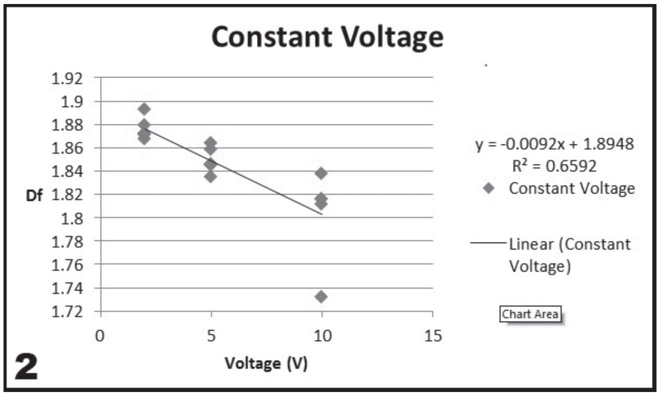

Figure 2: Fractal dimension for each constant voltage trial. The plot points to a strong downward trend.

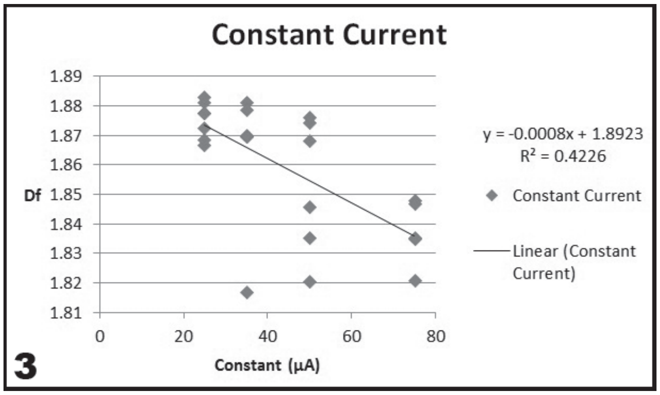

Figure 3: Fractal dimension for each constant current trial. While data is more scattered than the constant voltage trials, the same trend is prominent.

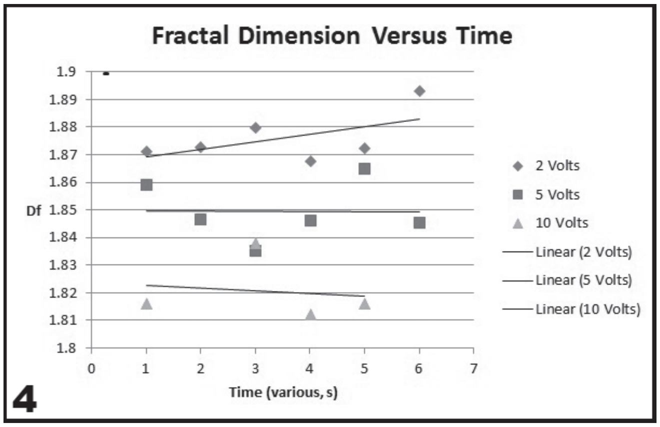

Figure 4: Fractal dimension versus time. The time scales vary depending on the voltage. For 2 volts, the times tested were every minute, for 5 volts every 30 seconds, and 10 volts was every 10 sec.

For each voltage and current tested, the fractal dimension to time relationship was tested. Figure 4 shows this relationship for the constant voltage trials only. It was obvious that no clear trend existed with respect to time. The dendrites were not growing far enough to cause any difference compared to the randomness of the sampling. If more exact methods were used, it would make sense for the fractal dimension to have a slight decrease with respect to time.

Future Work:

The data gotten from the above experimental procedure is useful for silver electrodeposits grown in de-ionized water at room temperature. However, if any of these constraints change, more testing will need to be done. The effect of temperature on dendrite growth would also seem to be a more sensitive way of controlling the formation.

Acknowledgments:

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