

Fabrication of Dendritic Electrodes for Electroactive Polymer Actuators

Nathaniel Hoglebe
Chemical Engineering, University of Dayton

NNIN iREU Site: Interuniversity Microelectronics Center (IMEC), Leuven, Belgium

NNIN iREU Principal Investigator(s): Dr. Hercules Neves, IMEC, Leuven, Belgium

NNIN iREU Mentor(s): Dr. Michael De Volder, IMEC, Leuven, Belgium

Contact: nathaniel.hoglebe@gmail.com, herc@imec.be, devol@imec.be

NNIN iREU Program

Abstract:

Dendritic microchannels were successfully created by the chemical dissolution of calcium sulfate dihydrate with water. In a second step, the negative shape of the channels was replicated by polydimethylsiloxane (PDMS) or a eutectic bismuth tin alloy. A proof of concept was delivered, although procedural difficulties prevented optimum results from being obtained. The low-melting metal offered the most promising results, and future work will attempt to improve on these methods to obtain tree-like electrodes with sub-micron branches.

Introduction:

Polymeric hydrogels can be tailored to respond physically to an applied voltage. An induced electric field causes them to either uptake or expel water, resulting in a physical expansion or contraction of the gel's overall shape [1]. Because of their controllable shape and biocompatibility, these gels can function as actuators in biochemical systems. One problem in implementing hydrogels, however, lies in the fact that their mechanical properties can become compromised if rigid electrodes are used to apply the electrical field. As the gel changes size, the non-uniform electric field and the localized stress around fixed electrodes either constrains the expansion of the hydrogel or causes the electrodes or gel to tear.

In order to solve this problem, a network of electrodes that moves with the expansion and contraction of the gel must be developed. As previously shown in literature, the chemical dissolution of plaster with water can be used to create fractal patterns [2]. These structures can then be molded to create positive casts of flexible, tree-like electrodes.

Experimental Procedure:

Calcium sulfate dihydrate ($\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$), commonly referred to as gypsum, was first heated to over 150°C to dehydrate the crystalline structure to ordinary Plaster of Paris ($\text{CaSO}_4 \cdot 0.5\text{H}_2\text{O}$). Water was then mixed with the plaster in a 5:4 ratio by weight. The mixture was poured onto a 100 mm diameter metal plate with premade arrays of

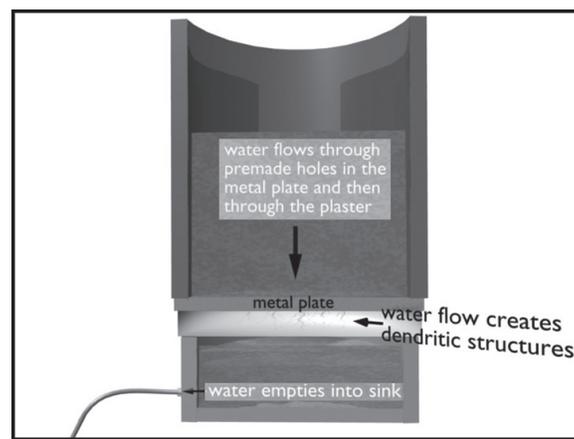


Figure 1: Setup for fabricating fractal patterns in plaster.



Figure 2: Dendritic structures created in plaster.

1 mm and $400 \mu\text{m}$ holes. After the plaster hardened, water was forced through the holes into the plaster via a reservoir on top of the plate. The size of the resulting fractal channels varied according to both the hole size of the metal plate and the pressure at which the water was injected. This water pressure was controlled by simply varying the height of the reservoir. Once the dendritic structures had formed, the plaster was removed from the plate. It was then baked again at over 150°C to dehydrate the crystalline structure back to $\text{CaSO}_4 \cdot 0.5\text{H}_2\text{O}$. This allowed for easy removal of the plaster from the molding material by placing it in water.

Two molding materials were used to create positive casts from the negative plaster molds. PDMS was poured into the channels, and the results of curing it under vacuum and at atmospheric pressure were compared. In the second method of casting, a eutectic bismuth tin alloy was melted and cast into the channels under pressure. Once the molding materials had hardened, the dehydrated plaster was placed in water to remove it from the dendritic structures.

Results and Conclusions:

Fractal structures were successfully fabricated within the plaster. The combination of a diffusion-limited chemical reaction between the water and plaster and the flow of the water through the porous media resulted in these branching structures [3]. The amount of branching was controlled by altering the force at which the water was pushed through the plaster. Higher pressures and longer flow times resulted in larger channels. In addition, structures created through the larger holes of the metal plate resulted in bigger structures.

Several problems were encountered when attempting to cast these structures due to the inherent porosity of the plaster. When casted under vacuum conditions, the low viscosity 184 PDMS entered not only the fabricated channels, but also the small pores within the plaster, making it impossible to separate the two materials. The high viscosity 186 PDMS, on the other hand, was unable to enter all the smaller channels. When the 184 PDMS was casted under atmospheric conditions, the tree-like structures could be removed manually from the plaster. When viewed under the scanning electron microscope (SEM), however, it could be seen that the plaster was still sticking to the PDMS, making the branches thicker and the fractal pattern less pronounced.

In order to solve these issues, a eutectic bismuth tin alloy was melted and cast into the channels under pressure. The molten metal was able to penetrate the larger channels and create free-standing structures that possessed high strength and yet flexibility due to the ductile characteristics of the material.

As a result of the crude nature of the injection setup, however, proper molding of the smaller channels was not achieved. Nevertheless, some of these initial experiments created free-standing micron-scale structures as well as branching formations, hereby providing a proof of concept for the proposed fabrication process.

Future Work:

A more advanced setup for the insertion of the molten metal into the plaster channels will be constructed in order to increase the injection pressure, resulting in a greater number of small branches. The goal of this future setup is to create tree-like electrodes with branch dimensions below $5\ \mu\text{m}$ and implement them within electroactive hydrogels.

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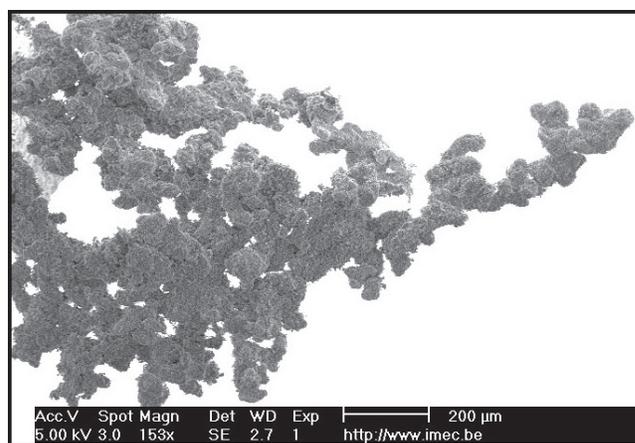


Figure 3: SEM of a PDMS tree casted from the plaster mold.

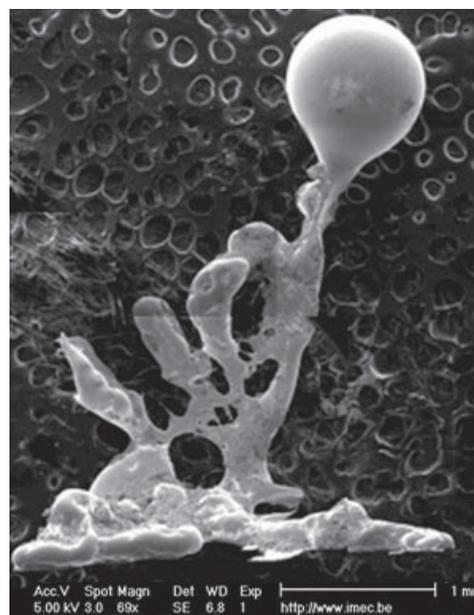


Figure 4: Bismuth tin alloy cast of a dendritic structure.