3D-Printing Pluronic F-127 Lattices to Spray with Methylcellulose Nanowires and Encapsulate with Agarose Gel

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Abstract

Pluronic-F127 gel lattices were printed on preheated silicon wafers using a modified 3D printer. The sample was then sprayed with a solution of methylcellulose to form methylcellulose nanowires, and hot agarose gel was poured on top of the lattice in order to encapsulate it. The agarose gel was then allowed to solidify and was carefully removed, leaving the impression of the lattice in the gel. The lattice structure was chosen so that the process could be tested on a small, somewhat complex structure. This method can be used for creating sophisticated models of the human vascular system, and for other applications, such as creating artificial human organs using 3D printing techniques.

Background and Methods

Being able to 3D print models of the human vasculature system would allow for more complex models to be created, which could be used in a variety of applications. One way that this technology could be applied is to creating human organs using 3D printing techniques, which could increase the likelihood of successful manned deep-space missions because of the lack of organ donors available to astronauts under such circumstances. We wished to replicate and improve upon the production of a 3D printed Pluronic F-127 structure, which would later be encapsulated by a gel solution and used as a template, so that an imprint of the structure remains in it after it is removed. [1] We improved upon this by spraying a thin coat of material onto the Pluronic F-127 structure, which was then deposited into the imprint left on the encapsulant. A Creality Ender 3 3D printer was modified to include a syringe. The extruder motor was used to apply pressure to the plunger of the syringe, which then pushed material from the needle tip. [2] In this way, a Pluronic F-127 10 weight percent (wt%) solution was printed. Pluronic F-127 gels between 25 and 35ºC and is a liquid at room temperature. The printed gel structure was then placed on a hot plate and sprayed with a solution of methylcellulose (MC) using electrospray deposition (ESD), which is a coating process achieved by spraying a solution from a needle tip through an electric field. This process is utilized for three dimensional coatings. [3] MC has been shown to form nanowires during spray. [4] The sample was then covered with a hot, liquid agarose gel, which was allowed to cool and harden for about 10 minutes. The printed structure acts as a disposable template for the agarose encapsulant, and is also used to deposit the sprayed material, which can either be left in as a coating for the interior template, or, as in the case with MC, removed. It remains an open question as to whether the structure of the MC can also act as a template, leaving its inverted imprint in the encapsulating gel.

Figure 1: Encapsulation of the lattice which was sprayed with the blue-dyed shellac (left) and which was sprayed with the methylcellulose solution (right).

References

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Research Conducted

The modified printer was used to print 10 wt% Pluronic F-127, made using a 2 wt% KCl and distilled water solution instead of plain distilled water. The salt in the solution was used to make the material more conductive. A lattice of this material was then printed directly onto a silicon wafer. The silicon wafer was then heated to 35ºC and electrospray deposition was used to spray the sample, first with a 1 wt% shellac solution, dyed with oil blue dye, to test the encapsulation process, and then later with an MC solution. Originally, the material was printed onto glass slides, which were then placed onto a silicon wafer before spraying, but we discovered that when the sample was printed directly onto the silicon wafer it was more conductive and allowed more material to be deposited during spray. The difference between the coating of a sample printed directly onto a silicon wafer and the coating of a sample printed onto a glass slide can be seen in Figure 2. Microscopic images of the samples were then captured to ensure that the Pluronic F-127 structure was coated by the spray material. Figure 3 shows microscopic images of the blue-dyed shellac particles that were deposited onto the structure. While the optical microscope images could not resolve the spray morphology, optical scattering was taken as an indicator that nanoparticles and wires were being sprayed as opposed to dense films. Next, a hot 1 wt% agarose solution was poured over the structure and allowed to cool in order to create a mold of the printed structure. Because Pluronic F-127 gel solidifies when heated to a temperature between 25 and 35ºC, and the agarose solution gels between 34 and 38ºC, the complementary nature of the two gels facilitated encapsulation. The solid agarose was then peeled off, and an imprint of the Pluronic F-127 structure was left in it, along with the material sprayed onto the original lattice; this feature can be seen more easily when observing the encapsulations that were made using the blue-dyed shellac spray, as shown in Figure 1.

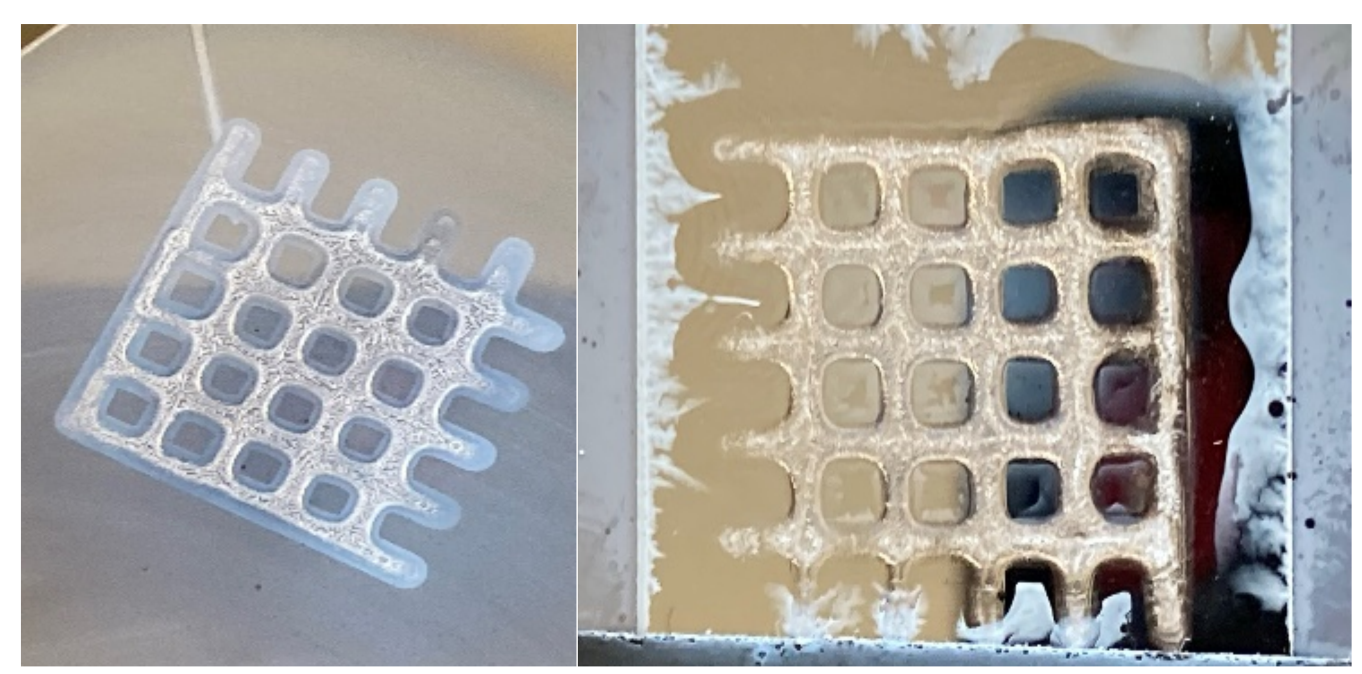

Figure 2: A sample printed directly onto a silicon wafer (left) versus a sample printed onto a glass slide (right). Both samples were sprayed with the methylcellulose solution.

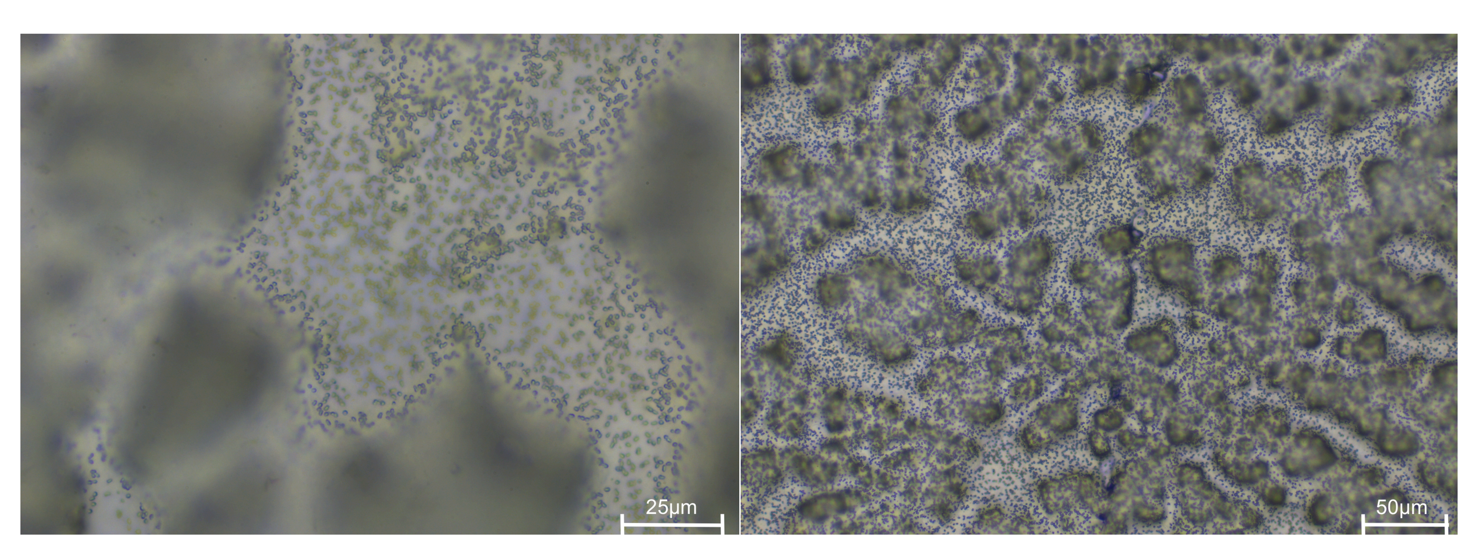

Figure 3: Microscopic images of the Pluronic F-127 structure sprayed with shellac imaged at 50x magnification (left) and 20x magnification (right). Scale bars indicate 25µm (left) and 50µm (right).

Results

While experimenting with spraying the prints, it was found that the structures printed directly onto silicon wafers were coated most effectively. The difference between the samples that were printed onto glass slides and those that were printed directly onto silicon wafers can be seen in Figure 2. Although the shellac particles were clearly deposited onto the Pluronic F-127 structure, as can be seen in the microscopic images, it is less clear whether the MC solution was efficiently deposited. The reason that the shellac particles are more easily seen than the MC may be because of the difference in their sizes. The thickness of the MC nanowires have been shown to be significantly less than 1µm. [4] The shellac droplets, on the other hand, are larger than that, as is shown in Figure 2. The comparison between the two samples can be seen in Figure 4 below. The agarose gel encapsulated the lattice structure and was able to maintain its shape after being removed from the structure, as seen in Figure 1. When removed, the blue-dyed shellac could be seen in the grooves of the imprint in the agarose. Our results show that the structure should be printed directly onto the silicon wafer to improve the coating of the lattice and that the silicon wafer should also be preheated to 35ºC to ensure that the Pluronic F-127 gel remains firm during the printing process.

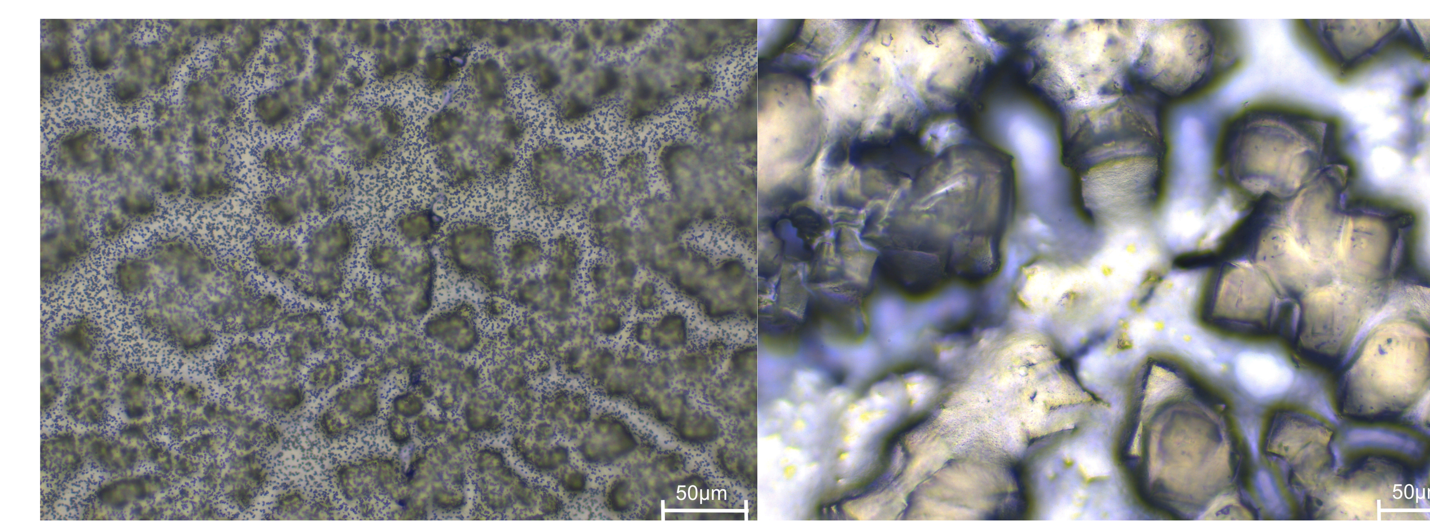

Figure 4: Pluronic F-127 lattices sprayed with the blue-dyed shellac (left) and the MC solution (right), both imaged at 20x magnification. Both scale bars indicate 50µm.

Conclusion and Future Work

Pluronic F-127 lattices were successfully printed using modified 3D printer. These lattices were printed directly onto a silicon wafer, which was then sprayed with either a shellac or MC solution using ESD. The structure was then encapsulated with agarose gel, and when the encapsulant was removed, an imprint of the structure was successfully captured in it. The shellac solution was successfully deposited onto the lattices, and the prints sprayed with shellac also successfully deposited the shellac into the imprint of the agarose, as can be seen in Figure 1. More investigation into spraying with the MC solution is recommended, as it is less clear whether the MC solution was efficiently deposited; using longer spray times and imaging the sample before and after spray might make the changes on the sample easier to observe. While mechanical peeling was used in this case, solvent etching would likely be better for removing the MC or shellac, but this will require we use gels that can also form chemical crosslinks, like gelatin methyacrylate. [1] In the future, this work could lead to the construction of detailed models of vascular structures and creating artificial human organs using 3D printing techniques.

Acknowledgments

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