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The Analysis of Microdroplet Arrays

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Abstract

The primary objective of my research this semester was the investigation into the optimization of the micropillar array both through simulations and physical testing. Where ancillary objectives include the familiarization of SEM imaging, Surface Evolver, and COMSOL. Significant progress has been made in all these objectives. Specifically in the construction of different asymmetrical droplets that were combined to form an array.

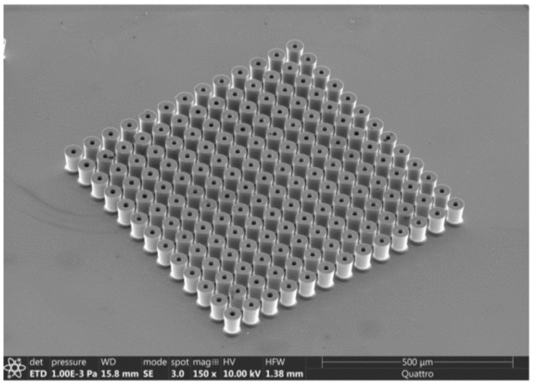
Introduction

The semester began with an analysis of the Particle Swarm Optimization theory. This theory is based on the social behavior of bird flocks and fish schools and was developed for solving optimization problems [1]. What these groups of animals have in common is that they both search for the most desirable regions of an area. They do this by constantly sharing the best fit information with each other. Which means that not only is each individual bird or fish gathering information about the region but this information is being shared with the group. So that collectively they can find the group-best location. Applying this to an algorithm means that the flock/school is represented as a swarm while each individual bird/fish a particle [2].

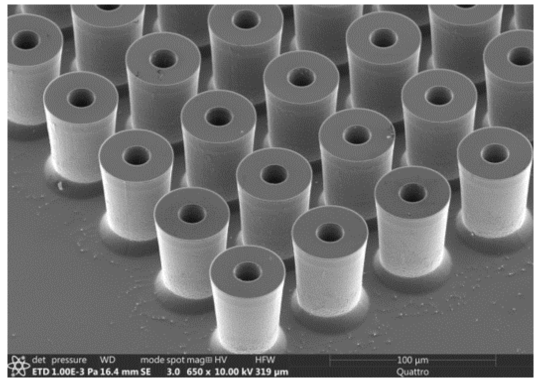
Each particle in the swarm has a position inside the region and is given an initial velocity. Care must be taken here to ensure that a certain level of randomness is used not only for positioning but also for the velocity. It is obvious as to why it is not desirable to have the swarm start out bunched up in one spot but it may not be as obvious to also introduce randomness into its velocity. After the initial velocity the particle then moves based on two things: the group-best position and the individual-best position. It is easier to think of these two things as velocity vectors. Where the final velocity is the addition of the group-best velocity vector and the individual-best velocity vector [3]. So now the user can manipulate the strength of each velocity vector to manipulate the final velocity. If the group-best or the individual-best velocity vector is too strong then the swarm might miss the actual best position or might never converge. This is why a certain amount of randomness should be added into the velocity vector.

The focus of this research is to develop an optimized cooling system using micropillar arrays. Using what we already know – namely that asymmetrical droplets have a higher heat coefficient then symmetrical ones based on the increase of the thin film liquid region – we constructed an array of the asymmetrical droplets. This array was then photographed using the SEM imaging machine.

The SEM imaging machine scans a focused electron beam over a surface to create an image where the electrons then interact with the sample to produce various signals. These signals are then collected by one or more detectors to form images of the sample [4]. Below in Fig. 1 are some images taken of our optimized microdroplet arrays.



(a) Zoomed-Out Shot.

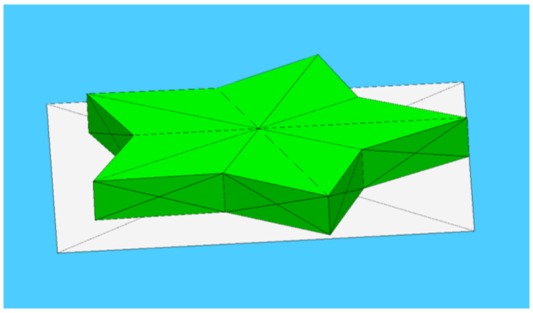


(b) Zoomed-In Shot.

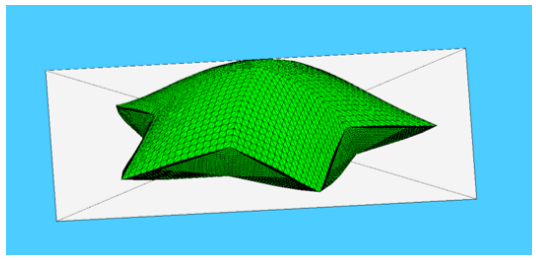
Figure 1 Photos taken with ESEM.

In between imaging array samples, I constructed additional asymmetrical droplets using Surface Evolver to be tested with COMSOL. The asymmetrical droplet that I primarily focused on was the star-shaped droplet. The reason behind picking this shape was the same reason behind why the triangle had a higher heat transfer coefficient than the already previously tested circle and square – the increased thin film region. Knowing that the thin film region of any microdroplet produces the highest heat transfer coefficient it is obvious to see that by increasing the area of this thin film region, we are increasing the heat transfer coefficient of the droplet.

This means that if by increasing the amount of corners, we are increasing the area of the thin film region, then we are also increasing the heat transfer coefficient. Since a 5-pointed star has more corners than a triangle, it is worthwhile to construct and test this shape. As one can imagine, the construction of this star wasn't as straightforward as the construction of a square or triangle. However, it was possible and shown in Fig. 2 is an image of the star before and after running the simulation through Surface Evolver.



(a) Before Running Surface Evolver.



(b) After Running Surface Evolver.

Figure 2 Surface Evolver droplet generation.

An interesting point of note is what was discovered when running our COMSOL simulations for our droplets. After the droplet was constructed it was sent to COMSOL to have a mesh developed on its surface. Once the mesh is developed the evaporation process can be analyzed in a steady-state condition. Where the heat transport is attributed to both conduction and convection. But was found out was that convection can be totally ignored when running our simulations. The convection current is made up by the Peclet number (Pe), the Rayleigh number (Ra), and the Marangoni Number (Ma). In other studies it was found that both the Peclet and Rayleigh numbers are so small that they can be neglected [6]. It was also found that the Marangoni number can be neglected for droplets with a volume of larger than 1 nL [7]. Which means that the only heat transport used in our COMSOL simulations is the conduction. Which is inversely proportional to the liquid film thickness [8]

Materials and Methods

The primary tools investigated this semester was the SEM imaging machine and Surface Evolver. Surface Evolver is a program that minimizes the energy of a surface subject to constraints like surface tension. The minimization is done by evolving the surface down the energy gradient [8]. Through the use of Surface Evolver the droplet shape can be formed and then transferred elsewhere for analysis. Once constructed, the droplet shapes are imported into COMSOL. COMSOL is then used to analyze the droplet shape made by Surface Evolver. COMSOL then defines a mesh around the droplet shape in order to run computations on it to produce curvatures at every point on the surface.

1 Results

While not every goal was met this semester, an analysis of the optimization of micropillar arrays was understood. Imaging and construction of asymmetrical droplet arrays were made. A further understanding of evaporation and the optimization of heat transfer coefficient on droplets was accomplished. And computer programs such as Surface Evolver and COMSOL were familiarized with.

2 Future Directions

The constructed asymmetrical droplets will be further analyzed using COMSOL and constructed. This will be done with hopes to find the most optimized shape that can produce the highest heat transfer coefficient. While also being able to be feasibly constructed. A current limitation seems to be the fabrication of such complicated shapes in the cleaning room. Of the currently fabricated arrays, further testing is required for validation.

References

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A Appendix

A.1 Raw Data.