SLATT UNDERGRADUATE RESEARCH FELLOWSHIP
FINAL REPORT

SCHOLAR NAME:	Thomas Kasl
FACULTY ADVISOR:	William Phillip
PROJECT PERIOD:	Winter Session 2020-2021
PROJECT TITLE:	3D-Printing Hierarchical Nanostructure Absorbance for Contaminant Removal and Resource Recovery
CONNECTION TO ONE OR MORE ENERGY-RELATED RESEARCH AREAS (CHECK ALL THAT APPLY):	**(x) Energy Conversion and Efficiency** **( ) Sustainable and Secure Nuclear** **( ) Smart Storage and Distribution** **( ) Transformation Solar** **( ) Sustainable Bio/Fossil Fuels** **( ) Transformative Wind**

MAJOR GOALS AND ACCOMPLISHMENTS

Summarize your research goals and provide a brief statement of your accomplishments (no more than 1-2 sentences). Indicate whether you were able to accomplish your goals by estimating the percentage completed for each one. Use the next page for your written report.

RESEARCH GOALS	ACTUAL PERFORMANCE AND ACCOMPLISHMENTS	% OF GOAL COMPLETED
Create a schematic of our custom 3D-printing set-up.	An assembly was created in Solidworks containing all the relevant parts of the printing setup (e.g. X/Y stage, syringe pump, needle, needle-holder).	100%
Prepare images from 3D-schematic for integration into the first figure for the research paper.	Using the 3D models that I created, I was able to produce desirable images for a figure. Going forward, as I continue to work on this project, I will produce more images as necessary for the writing and publication process.	90%
Perform profilometry on 3D-printed membranes.	Using the Bruker DektakXT profilometer located in the Materials Characterization Facility, I was able to produce surface scans of single-layer, 3D-printed polymer strands to verify the precision of our printing technique. The data that I have collected should be sufficient to support a figure in the paper showing the controllable microstructure of the printed filaments.	90%
Functionalize membranes with PEI and Terpyridine moieties	This work was done primarily by Jialing Xu, but I will list it here because it is relevant to the progression of this project. Printed membranes have been successfully functionalized with PEI and Terp and verified by FTIR.	100%
Survey literature for sources relevant to our research to provide background for the writing process.	During a period of quarantine, I spent significant time compiling literature sources that would provide a baseline for the writing process of the introduction for the paper.	100%
Learn and perform copper binding experiments with concentration analysis by UV-vis spectroscopy	Following a protocol from a paper previously worked on by the Phillip Group, I performed a short series of copper binding experiments on an array of membranes with varying thicknesses and functionalization. I gained knowledge about how to run the UV-vis spectrometer.	90%

RESEARCH OUTPUT

Please provide any output that may have resulted from your research project. You may leave any and all categories blank or check with your faculty advisor if you are unsure how to respond.

CATEGORY	INFORMATION
EXTERNAL PROPOSALS SUBMITTED	
EXTERNAL AWARDS RECEIVED	
JOURNAL ARTICLES IN PROCESS OR PUBLISHED	In the process of writing a journal article, for further details, please contact Prof. Phillip.
BOOKS AND CHAPTERS RELATED TO YOUR RESEARCH	
PUBLIC PRESENTATIONS YOU MADE ABOUT YOUR RESEARCH	
AWARDS OR RECOGNITIONS YOU RECEIVED FOR YOUR RESEARCH PROJECT	
INTERNAL COLLABORATIONS FOSTERED	
EXTERNAL COLLABORATIONS FOSTERED	

WEBSITE(S) FEATURING RESEARCH PROJECT	
OTHER PRODUCTS AND SERVICES (e.g., media reports, databases, software, models, curricula, instruments, education programs, outreach for ND Energy and other groups)	

RESEARCH EXPERIENCE Please let us know what you thought of your research experience: Did this experience meet your expectations? Were lab personnel helpful and responsive to your needs? What else could have been done to improve your experience or achieve additional results?
My research experience over this Winter Session was very valuable in allowing me to continue working on this project. Overall, this research experience met my expectations, but some external factors limited the progress that I was able to achieve. I was quarantined for 10 days during the middle of the Winter Session and slowed down my work on gathering data via profilometry, but I was able to make up some of that time at the end of the month. Since I had already been working within the Phillip lab for some time, the lab personnel were unsurprisingly helpful and able to help me with my needs. I had already had a good idea of how to work within the lab, so I did not need very much help with my work. Since I was only working 20 hours a week for the lab, my progress was more limited than if I had been working full time. My experience might have been improved if I had been able to work full time and have undivided attention to making progress in the lab.

FINAL WRITTEN REPORT

(Please use the space below to describe your research project and objectives, any findings and results you can share, and graphs, charts, and other visuals to help us understand what you achieved as a result of this research experience.)

The main goal of the research project I worked on over the Winter Session entitled: *3D-Printing Hierarchical Nanostructure Absorbance for Contaminant Removal and Resource Recovery,* was to produce data and figures to support the publishing of a paper relevant to the project. I have been working on this project in varying levels for more than two years now and previous effort had allowed us to repeatably print well-defined polymer membranes with finely tuned hierarchical structures. By taking advantage of non-Newtonian flow in a tri-copolymer solvent system with integral carbon nanotubes, we were able to overcome technical printing problems. The well-defined nanostructure of these printed membranes has been verified by SEM imaging and functionalization of the membranes with PEI and terpyridine was able to be verified by FTIR.

Over the Winter Session, my work on this project mainly consisted of producing figures for the article to be submitted in the coming months as well as performing profilometry scans of single layer printed membranes. Figure 1 shows a schematic of the custom 3D-printer setup that we use. A syringe pump is connected to an extrusion needle, with distance between the needle tip and the substrate controlled by a linear stage. The substrate is affixed to a metal plate with X/Y position controlled by a planar stage. The entire system is enclosed in a humidity chamber (not shown) and internal humidifier and humidity controller create a determined percent humidity environment.

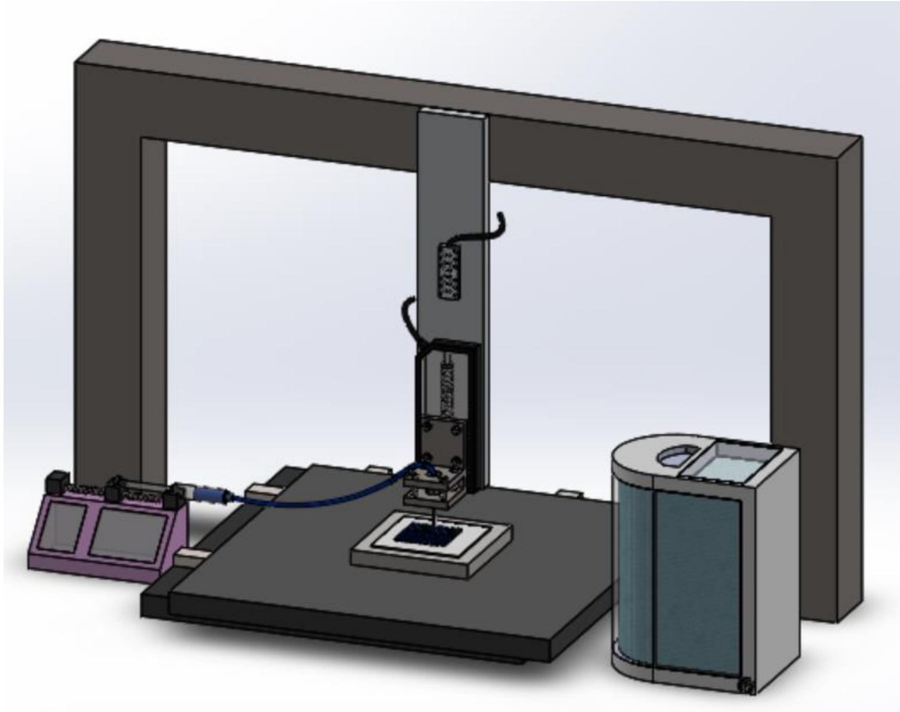

Figure 1. Schematic of the custom 3D-printer.

Figure 2 shows a close-up of the linear stage that controls the vertical height of the needle as well as showing the woodpile architecture used in printing the 3D-printed layers. This image or another like it will be used in the published paper to help explain our fabrication technique.

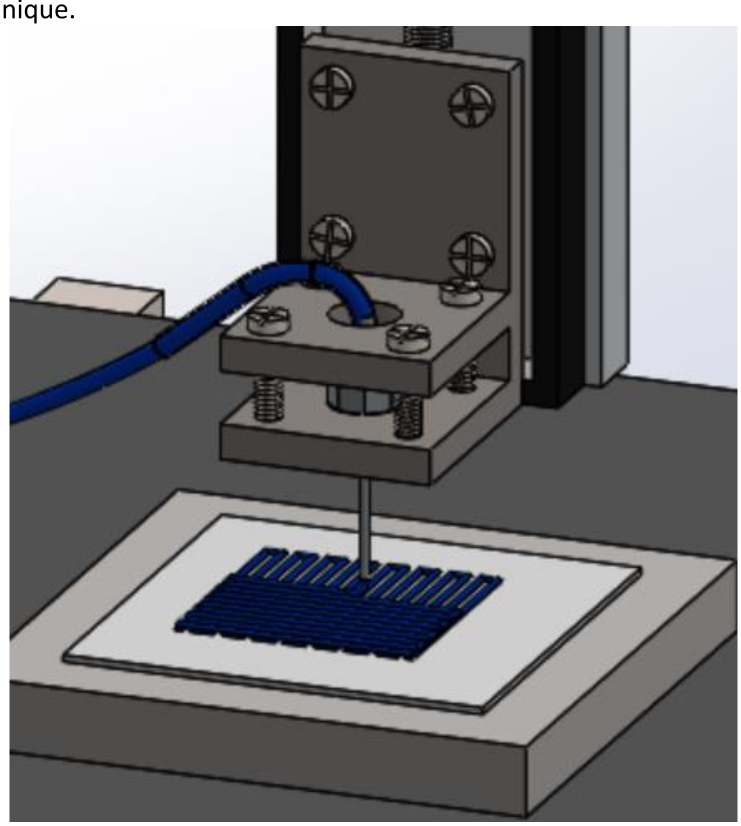

Figure 2. Woodpile architecture of 3D-printed layers.

Figure 3 shows a cross section of the X/Z plane of the printing surface. The needle is shown extruding the tri-copolymer solvent system in what would be the fifth layer of a printed membrane. The membranes are printed in this log cabin (crosshatch) style to improve the mechanical strength of structure as well to allow high porosity of the material.

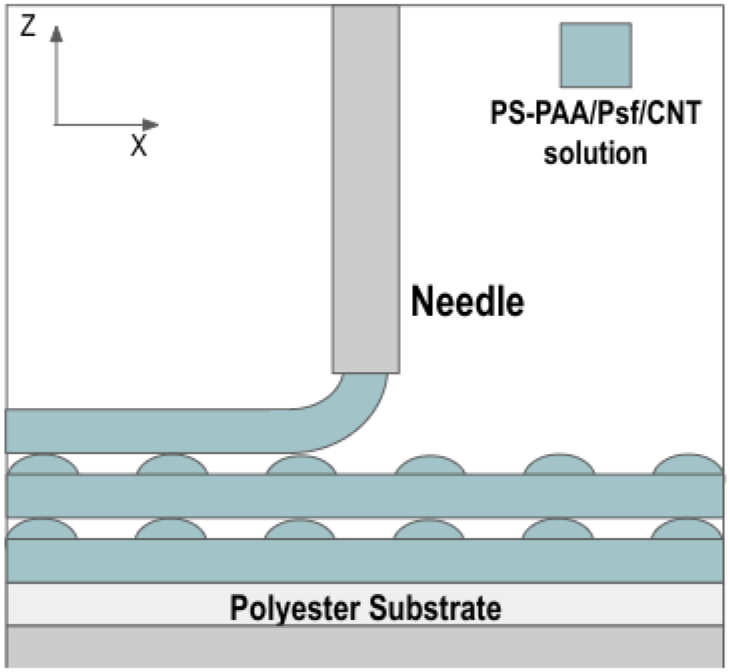

Figure 3. X/Z cross section of the printing surface.

In addition to preparing the above figures, I also validated the microstructure of the printed materials. Shown in Figure 4, a profilometry scan of a single layer of the tri-copolymer deposited on glass, shows the repeatable microstructure throughout a sample. An even distance between printed strand peaks of ~500 µm (0.5 mm) is seen in this scan. Our printer was programmed to print with 0.5 mm between strands. This scan confirms the ability of our system to produce a structure with predetermined parameters. In addition, a consistent thickness of ~3100 nm is seen throughout the scan.

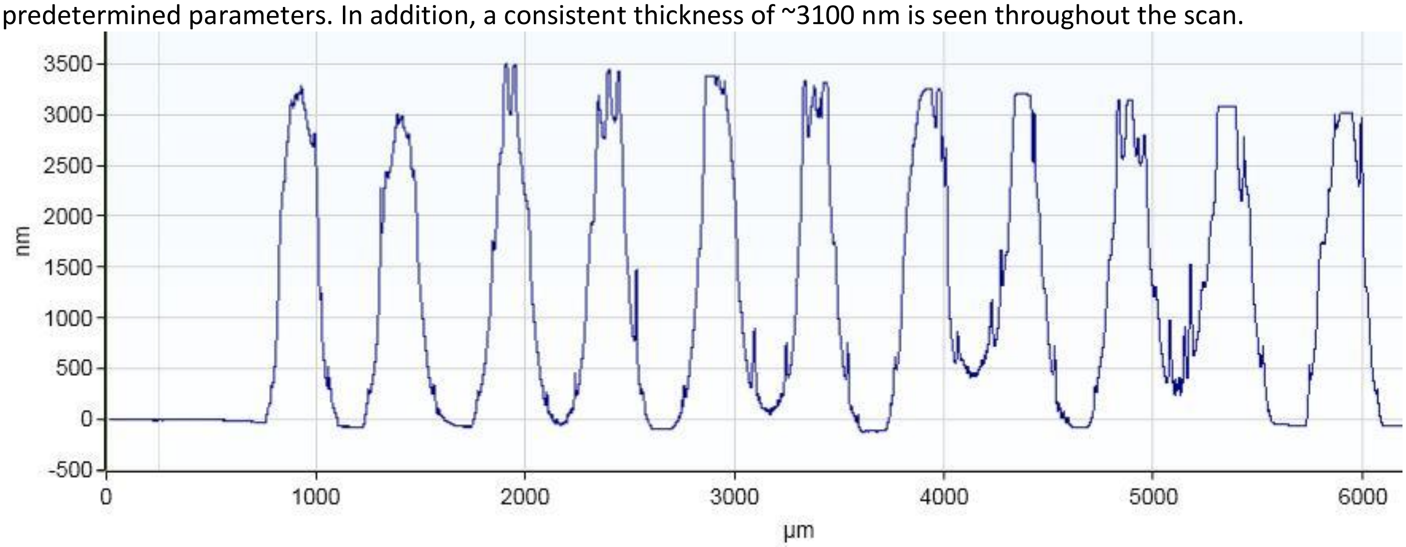

Figure 4. Profilometry scan of single-layer membrane printed on glass substrate.

Work still in progress on this project has shown promising high permeabilities and ability to bind copper ions in aqueous solutions. I will be continuing with this project during the spring semester, and we are planning to submit an article on the subject prior to start of the 2021-2022 school year. 3D-printing these types of membranes will allow us to have high porosity and therefore high energy efficiency-contaminant removal and resource recovery. Applications include nitrate recovery from fertilizer runoff; lead removal from contaminated water in areas such as Flint, MI; and heavy-metal ion recovery from industrial chemical processes. A further area of research may include co-axial extrusion of multiple printing solutions.