**GNG5140 Report Template**

**Design Development of Electroplating Using Open-Source 3D Printing Framework**

Submitted by

[3D Electroprinter]

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**Abstract**

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**List of Acronyms**

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| **Acronym** | **Definition** |
| FDM | Fused Deposition Modeling |
| SLA | Stereolithography |
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1. Introduction

The advent of additive manufacturing has assisted in the development of a multitude of different products that assist manufacturers and researchers alike in creating and exploring new designs. One such innovation is the merging of electroplating systems with 3D printing systems to create an electroplating device. While the current technology utilizes a bath, gel, or some other means of depositing plating onto a surface, the goal of this new surface engineering technique would be to selectively deposit material based on a given surface. To do this, the utilization of 3D printing technology is most apt, as this would allow for the 3D printer to perform X-Y-Z movement while the electroplating process is happening, allowing for extremely flexible and customizable plating surfaces. To the authors’ knowledge this has not been performed yet, and as such it requires preliminary research to perform feasibility analysis to assess the situation. The aim of this document is to provide a case for the feasibility of the current project and to provide parameters of current technologies to compare the design against. This will be conducted using the current literature available, as well as any commercial electroplating solutions that can be found. The aim of this portion of the report is to outline the desires of the client, examine similar solutions and technology and offer preliminary evidence of the feasibility and metrics that will govern the project. Currently there are a few similar technologies that the authors have identified, bath electroplating, 3D Printing of metal or plastic parts, and then the mixture of 3D Printing and electroplating [Lou, 2018] [Shang, 2017]. The last portion is a relatively large and varied part of this, as there are multiple avenues that utilize both 3D printing and electroplating, which will be the focus of this design deliverable.

1. Background

This initiative was started in Vietnam under “ECRIT” which had the goal of pursuing a more effective electroplating process for the work carried out under Bruce et al. Their work was pursuing hyper hydrophilic plating surfaces, but it was primarily hindered by the lack of controllable surface area. They concluded that if they could reduce the surface area of the plating process it might make the process itself more efficient. Thus came the idea of using 3D printing to minimize the surface area to control the plating process, effectively selectively plating only the portion that is desired. Not only would this innovation improve the work Dr. Bruce has been pursuing but this opens several options for commercial and hobbyist use. The goal is to utilize this design in the Makerspace at University of Ottawa, giving more free and easy access to electroplating to the student body and public alike.

1. Customer Needs

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| **Customer Requirement** | **Notes** |
| Creating an open source potentiostat | An open 3D printer is going to be used for the configuration  |
| Control of electrolyte mixing  | Plating of multiple materials required |
| Effective cleaning process  | Easy to maintain |
| Environmentally sustainable | The electrolyte is harmful and needs to be handled properly  |
| Contained and safe plating process | Safety must be taken into consideration  |
| Finite control of position and applied plating potential | We are analyzing different techniques that can be used for this purpose |

# Process Parameters

3D Electroplating technology requires a better understanding of the parameters involved in the part creation process. A 3D printer and Electroplating process are mated together for this case. In this section we are going to review the different parameters needed for the process.

* 1. 3D Printing Parameters

Due to our removal of the hot-end, filament, and feeder system the parameters that govern the system change drastically when compared to other printing methods. When 3D printing, a few crucial factors are print speed, layer height, hot end size, bed, and hot end temperature, among many other parameters based on the material being printed. Without a hot end, filament, and feeder many of these process parameters are taken out, but analogous parameters can be drawn from the changes we make. For example, print speed would stay the same, but something like hot end temperature or bed temperature would instead be electroplating bath temperature. The electroplating parameters will be discussed in later sections, and this section will cover the general parameters that we believe will govern our systems movement in the print space.

Print speed is an excellent example of a parameter that will stay relatively the same when it comes to the changes, as this print speed will not be the X speed and Y speed that the printer must take to plate the selected area. The point that will have to be covered here is that electroplating is a very slow process [Plowmanm 2015], which means it is essential for our team to focus on doing the opposite of what commercial printers are trying to do currently. The focus of the printer should not be to print quickly necessarily, while speed is important, it is more important to the electroplating process that the print speed is slow. It was found that long electroplating times created better hyper hydrophilic surfaces, which is a focus of our client [Garbarino, 2018]. This means that the print speed will need to be very slow to accommodate the chemical reactions that take place within the bath, which can only be accommodated by a few motors. The precision required for our process means that brushless motors and servo motors are likely not going to feature in our design as for the former they focus on fast speeds and the latter lack the precision that is required. This leaves step motors (which are commonly found in 3D printers commercially) and geared stepper motors. The geared stepper motor is just a step motor with an additional gearbox to add torque or speed to the motor. For the purpose of our design, we are likely to utilize a commercial printer with little modification as to keep this as accessible as possible. This means our design will likely utilize a stepper motor between 20-60 N\*cm which are the most common ones found on commercial printers. Step motors are advantageous due to their high precision when it comes to their positioning, with some having less than a degree of step changes. While these design parameters have been identified, the team is still early in the design process and as such these parameters are subject to change as the design itself is determined.

|  |  |
| --- | --- |
| Parameter | Value |
| Motor Torque | 20-60 [N\*cm] |
| Motor Type | Step Motor or Geared Stepper |
| Print Speed | Slow (< 1 $\frac{mm}{s}$) |

Table x: Summary of Initial 3D Printing Parameters Identified

* 1. Electroplating Parameters

The aim of this project is to create a device capable of creating a superhydrophillic porous nickel surface that is suitable for use in the electrolysis of water [Hao 2019]. Unfortunately, the exact set of conditions required for the formation of the fractal Ni surface are somewhat unclear. It has been known for a while [Plowmanm 2015] that electroplating must occur under significant overpotential for the necessary large bubbles to form, but quantitative descriptions of the necessary voltage are lacking. Most scientific publications on the matter operated their systems in galvanostatic mode (constant current density); Hao et al used a 2 mA/cm^2 current. [Trofimova, 2021] was able obtain a porous zinc structure at a current density of only 0.3 mA/cm^2 but they did not characterize it by the same methods as Hao, so it is unclear if that lower current density still yielded the desired properties. One hint at the voltage that is needed is a graduate thesis by uOttawa student Zhihao Zang in which they used porous hydrogen-templated Nickel as the first stage in a more complex electrode synthesis. This used a potential of 4 volts for electroplating and while it is unknown what current density, they used this gives the general range of voltages the electroplating controller should be able to achieve. Final parameters are subject to change, but for now the target is to be able to achieve 5 V to have some safety margin for controlling the electroplating, it seems safer to regulate by current density since that is a direct reflection of reaction rate.

|  |  |
| --- | --- |
| Parameter | Value |
| Plating contact angle with water | <25° |
| Electroplating current density | 2 mAh/cm^2 |
| Max electroplating operating voltage | 5 V |

1. **Potential Design Options**

Nickel chloride idea, active versus passive anode, “injection” anode idea, etc. A major decision to be made is whether the anode (AKA Counter-electrode) should be made of a relatively inert material such as graphite, or if it should be made from Nickel metal. All laboratory-scale research on hydrogen bubble templating is done with an inert anode, while in industrial-scale electroplating applications nickel anodes are used. These anodes are “active” in the sense that nickel metal atoms become ionized and enter the solution, from which they are then transferred to the cathode, to be electroplated. With an inert electrode the electroplating solution is the direct source of nickel atoms and gradually becomes depleted. Aside from ensuring a steady supply of nickel, an active anode can eliminate side reactions with the electrolyte (since the electrons exiting the electrolytic cell have to come from somewhere) that potentially can include noxious chlorine gas. The challenge that comes with an active anode is that is gets gradually used up over the course of plating. This means that the anode must periodically be replaced, and that its geometry may change over the course of printing which may be an issue with specifically needle-shaped cathodes discussed below. Depending on how fast it is used, it may require that the “print head” adjust its vertical position over the course of a single print.

The method by which the electroplating is kept confined to the small, desired area is important to figure out, but not straight forward. One possibility is the use of a standard electroplating bath covering the entire object to be plated. The anode would be a thin needle positioned very slightly above the worked object. The hope is that current would only travel through the short path directly from the needle tip to the object and hence localize the deposition of Nickel atoms to the are just under the anode. It is unknown how well this world work: Virtually all extant electroplating processes use symmetrical electrodes so information on how current in an electroplating bath spreads between electrodes of very different shapes is lacking. An alternate option is inspired by Shang, 2017. They used 3D printer modified with a syringe to coat alginate gel on a surface in desired shapes, while applying a voltage between the syringe and surface to induce cross-linked. Similarly, this 3D Printer could use a syringe needle to dispense very small amounts of electroplating solution onto the substrate only on the are intended for coating, while applying the necessary voltage. Aside from ensuring the coating stays confined, this also minimizes the amount of electroplating solution used per print: Environmentally and economically favorable. There are potential downsides: It would require a pumping system that can dispense the small precise volumes of solution necessary, which adds to cost and mechanical complexity and may be outside of the team’s expertise. There is also concern that the electroplating solution, unlike a gel, would spread out too readily on the substrate to print with the required precision.

One choice that will require further research is what the composition of the electrolyte bath should be. The papers published utilize either 0.1 or 0.2 Mol/L hydrated nickel chloride (NiCl2 \* 6 H2O) as the nickel salt and about 10 times that concentration of ammonium chloride (NH4Cl). The choice of salt has little impact with an active anode, but with an inert anode the chloride sees chlorine gas generated at the anode. Further research must be done to see if there exist nickel salts sufficiently soluble with a counterion that does not generate harmful gas when oxidized. The addition of an ammonium salt may not be possible to avoid: According to Zhang’s (2020) thesis, the ammonium ions are the main source of hydrogen for the large bubbles that are critical to the Hydrogen Bubble Templating procedure. This unfortunately means ammonia gas is generated at the cathode. This may not be replaceable, but some investigation should be done.

1. Conclusions and Recommendations for Future Work

As of now, the team has a strong understanding of how the project needs to move forward. The team plans to take the next step in proposing design solutions for the project, which will start with identifying our engineering or design requirements. These will come directly from the client’s customer requirements which will be prioritized from a 1-5 basis with a 1 being low priority, a 3 being medium priority and a 5 being high priority. After which the design requirements will be measured the same way. After this, we will combine our potential design ideas, and increase the design ideas by creating a weighted matrix to compare any future ideas we produce. These designs will be weighted based on the design requirements we outline in the future, and by next update a preliminary design will have been selected to move forward with.

1. Bibliography

[1] Q. Lou and R. Wu, “Integrated printing stereo antenna with dual materials 3D printing technology,” Electronics Letters, vol. 54, no. 3, pp. 118–120, Feb. 2018, doi: 10.1049/el.2017.4087.

[2] W. Shang et al., “Hybrid 3D printing and electrodeposition approach for controllable 3D alginate hydrogel formation,” Biofabrication, vol. 9, no. 2, p. 025032, Jun. 2017, doi: 10.1088/1758-5090/aa6ed8.

[3] K. A. Ohiri, N. M. Nowicki, T. J. Montalbano, M. Presley, and N. S. Lazarus, “Electroplating of Aerosol Jet‐Printed Silver Inks,” Advanced Engineering Materials, p. 2100362, Jun. 2021, doi: 10.1002/adem.202100362.

[4] “Electroplating 3D Printed Parts for High-Performance Antennas,” Formlabs. <https://formlabs.com/blog/electroplating-3d-printed-parts-high-performance-antennas/>.

[5] T. Mokabber, S. Rastegari, and H. Razavizadeh, “Effect of electroplating parameters on properties of Zn–nano-TiO2composite coatings,” Surface Engineering, vol. 29, no. 1, pp. 41–45, Feb. 2013, doi: 10.1179/1743294412y.0000000077.

[6] J. E. Hoffmann et al., “The influence of the electroplating parameters on the conditions of deposited nickel-iron coatings,” Materialwissenschaft und Werkstofftechnik, vol. 39, no. 3, pp. 209–216, Mar. 2008, doi: 10.1002/mawe.200800286.

[7] B. J. Plowman, L. A. Jones, and S. K. Bhargava, “Building with bubbles: the formation of high surface area honeycomb-like films via hydrogen bubble templated electrodeposition,” Chemical Communications, vol. 51, no. 21, pp. 4331–4346, 2015, doi: 10.1039/c4cc06638c.

[8] S. Garbarino, V. Charbonneau, N. Nzone Fomena, J. Gaudet, D. R. Bruce, and D. Guay, “Hydrogen Bubble Templating of Fractal Ni Foams for Water Oxidation in Alkaline Media,” ECS Meeting Abstracts, vol. MA2018-01, no. 29, pp. 1700–1700, Apr. 2018, doi: 10.1149/ma2018-01/29/1700.

[9]Hao, M., et al. “Hydrogen Bubble Templating of Fractal Ni Catalysts for Water Oxidation in Alkaline Media.” ACS Applied Energy Materials, vol. 2, no. 8, 30 July 2019, pp. 5734–5743, 10.1021/acsaem.9b00860.

[10] Trofimova, Tina-Tini S., et al. “Modeling of the Porous Nickel Deposits Formation and Assessing the Effect of Their Thickness on the Catalytic Properties toward the Hydrogen Evolution Reaction.” International Journal of Hydrogen Energy, vol. 46, no. 32, May 2021, pp. 16857–16867, 10.1016/j.ijhydene.2021.02.093.

[11] Zhang, Zhihao, and Olena Baranova. The Development of Three Dimensional Porous Nickel Materials and Their Catalytic Performance Towards Oxygen Evolution Reaction in Alkaline Media. Université d’Ottawa / University of Ottawa, 2020.