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Affordable Additive Manufacturing of Electrochemical Energy Conversion Devices

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Project Summary

The application of direct write additive manufacturing to production of electrochemical energy conversion devices, e.g. batteries and fuel cells, is a topic of rapidly growing interest. A recent example of micro-printing comes from the paper published by Sun *et al.* [1]. This article presents a Li-ion microbattery that was printed using lithium oxide-based inks. The battery itself is sub-millimeter in size and was shown to produce similar power densities to that of macroscale batteries of the same type. Printers that are capable of reproducing the experiments of Sun *et al.* are commercially available at considerable cost. More recently, research groups have explored developing their own printers capable of accomplish similar tasks for a fraction of the cost. Esposito *et al.* used a HP Deskjet 1000 inkjet printer to print dense electrolyte layers for solid oxide fuel cells [2]. The resolution of the deposited drops was approximately 100 µm. By using the work of Esposito *et al.* as an example further investigations are planned into the capability to produce electrochemical devices with low cost printing devices. Specifically, a tri-color ink cartridge from consumer printer will be modified to simultaneously print various materials relevant to electrochemical devices on a substrate. Two applications of this method are being explored: solid oxide fuel cell electrode microstructures that produce favorable chemical reaction kinetics and the titania (TiO_2) electrode layer of dye-sensitized solar cells.

It is necessary to understand the effects of ink formulation on the final geometry of the printed electrodes and develop a proper ink formulation for electrode fabrication. The electrode inks need to be colloidal mixtures with particle sizes small enough not to clog the print head. The viscosity of the inks will need to be assessed to produce consistent deposition and layering from the printer. This project focuses on understanding the effects of ink formulation of on printing various components of electrochemical devices. This formulation will impact ink viscosity, surface tension, and rate of drying and ultimately the structure of the printed devices. Consideration for the interaction of different inks being deposited at the same time will also need to be taken. The student researcher will contribute to the above efforts by performing a set of screening experiments to test the influence of ink formulation on electrode quality outcomes.

Student Duties

The student researcher will assist in several aspects of the project. Primary responsibilities will focus on preliminary evaluation of the influence of ink formulation on the quality of printed electrodes. The student will perform a brief literature survey to assess common parameters relevant to ink behavior, such as viscosity, particle size, and ratios of ink components (e.g., powders, solvents, and surfactants). The student researcher will then develop a basic design of experiments (DOE) to test the influence of relevant factors. The student researcher will then fabricate a series of test electrodes by depositing the ink on substrates. The fabricated electrodes will be produced following the DOE and electrode quality outcomes will be assessed. These outcomes may include layer uniformity, adhesion to the substrate, and observation of final microstructure.

In addition to the above primary responsibilities, the student researcher may assist with adaptation of a commercial inkjet printer for electrode ink deposition. Contributions in this area will be tailored based on the student researcher's interest and aptitude for mechanical, electronic, or computer programming work.

Several benefits can be expected from completion of the above tasks. In the first task the student researcher will be introduced to the basics of literature reviews for research purposes. Test matrix development based on findings from the literature review will introduce the student to statistical design of experiments concepts and related statistical analysis methods. The student researcher will also perform a number of basic laboratory tasks to support analysis efforts. Most notably materials preparation and handling experience will be gained. The opportunity for introduction to optical and electron microscopy and other materials characterization methods will be available.

Mentor Supervision and Interaction

The student researcher will work with the above faculty mentor and a graduate research assistant on the above project. The student researcher will have daily contact with the graduate research assistant during a standard work week. The student researcher will have several interactions with the faculty mentor during the week as well. These interactions will include a weekly one-on-one meeting with the faculty mentor, weekly research group meetings, and regular lab sessions with the faculty mentor and graduate assistant present.

During one-on-one meetings the student researcher will be expected to provide a brief weekly update on progress, challenges, and plans for the coming week. Additional discussion of research methods and career interests will be handled during these meetings as well. At the end of the first three weeks of the research project the student will be expected to provide a brief presentation on their literature review efforts and planned activities for the remainder of the summer. This presentation will be given at a broader research group meeting. At the end of the summer, the student researcher will be expected to provide a presentation to the research group summarizing their efforts and findings. Student researcher performance will be evaluated based on the following criteria:

- Does the student effectively identify challenges in the course of the project?
- Does the student plan accordingly to address these challenges and make progress?
- Is the student responsive to suggestions from the mentor and research group members?
- Does the student effectively communicate their findings?
- Did the student meet the project objectives?

References

[1] K. Sun, T.-S. Wei, B.Y. Ahn, J.Y. Seo, S.J. Dillon, J.A. Lewis, Adv. Mater. 25 (2013) 4539.
[2] V. Esposito, C. Gadea, J. Hjelm, D. Marani, Q. Hu, K. Agersted, S. Ramousse, S.H. Jensen, J. Power Sources 273 (2015) 89.