ND*nano* Undergraduate Research Fellowship (NURF)
2015 Project Summary

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Project: Nanoparticle synthesis for fabrication of 3D solid-state batteries

4. Briefly describe any new skills you acquired during your summer research:

During my research experience I learned how to use a number of tools. Starting with the necessary chemical precursors, I was taught how to synthesize powder by solid state and chemical routes, use a ball mill and high energy mills, program and use high temperature furnaces, use powder dies and a hydraulic press, and synthesize ceramic slips and cast them with a tape-casting machine to construct a solid-state electrolyte from scratch. I also learned the basics of x-ray diffraction and used an x-ray diffractometer to determine the crystallographic properties of a given sample. X-ray fluorescence spectrometry was used to find the chemical composition of samples.

5. Briefly share a practical application/end use of your research:

This research project is focused on attaining a practical application in the automotive sector. Solid-state batteries are much safer than the popular liquid or polymer-based lithium-ion batteries currently used in electric vehicles. Liquid-based batteries are dangerous because they are flammable and are prone to bursting if damaged. By replacing the liquid with a solid oxide, there is a reduced risk of ignition of the cell since the electrolyte is non-flammable. Higher performance anodes and cathodes can also be used, increasing energy density. Solid-state batteries could make electric vehicles safer and more common.

Project Summary:

Currently, the most common rechargeable battery technology is the liquid or polymer lithium-ion cell. These cells utilize a liquid or polymer electrolyte which allows lithium-ions to flow between the anode and the cathode.

Unfortunately, the liquid electrolytes used are also associated with certain safety hazards. In the event of a short circuit, a great deal of heat can be generated inside the cell, leading to electrolyte ignition and/or an increase in pressure until the cell bursts. This could be prevented by development of a solid-state battery with a solid oxide electrolyte. This thin, solid, non-flammable, ion-conducting sheet separates the anode and cathode so that in instances of cell damage the risk of ignition or explosion of the cell is greatly reduced.

The target material to use as a solid electrolyte is the ceramic compound $Li_7La_3Zr_2O_{12}$ (LLZO) which has ionic conductivity sufficient for use in batteries. As an oxide material, LLZO must be sintered at a high temperature. For this to be economical, the LLZO should be tape-cast into thin sheets before using it in a cell. The challenge of the project is to reduce the sintering temperature below 900°C so that Li is not lost during processing. Experiments were conducted to a) discover how to process nanosize powder and additives to effectively reduce the sintering temperature of the LLZO to avoid Li losses and b) develop a low cost process for manufacturing thin electrolyte sheets.

We were able to reduce the standard LLZO sintering temperature by about 300°C from 1200°C to 890°C, allowing greater Li retention. This was done by milling to create 50nm diameter powder and adding alumina (Al_2O_3) and lithium borate (Li_3BO_3) glass in small amounts to the LLZO. The Al_2O_3 stabilizes the preferred LLZO crystal structure, and the Li_3BO_3 melts at lower temperatures than LLZO to promote sintering. More research is needed to determine how to increase the density of LLZO which would increase ionic conductivity to sufficient levels. Progress was made with the tape-casting system. Multiple compositions were tested, with one or two showing desirable results. Minor adjustments need to be made to make cast tapes homogeneous and smooth. Through this research, I learned the basics of a technology that has an ambitious practical application. I look forward to seeing the successful development of solid-state batteries and the benefits they provide.

Publications (papers/posters/presentations):

Poster presented at Summer Undergraduate Research Symposium, July 31, 2015.