NDnano
Notre Dame Nanoscience and Technology

NDnano Summer Undergraduate Research 2024 Project Summary

1. Student name & home university:

    Sándor Henrik Sipos, Budapest University of Technology and Economics

2. ND faculty name & department:

    Prof. László Forró, Stavropoulos Center for Complex Quantum Matter
    Dr. Dávid Beke, Stavropoulos Center for Complex Quantum Matter

3. Summer project title:

    Development of perovskite based solar cells

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

- I learned the theoretical and practical background of solar cell technology, why perovskite-based technology is the most promising area to research in photovoltaics
- Electron spin resonance spectroscopy
- Raman spectroscopy
- X-ray diffraction techniques
- I learned how to grow single crystals and create nanocrystalline solutions with precipitation processes.
- Learned the spin coating process of thin films and measuring the thickness with a profilometer.
- UV-Vis spectroscopy for powders and films

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

    Perovskite based solar cells are the candidates to replace the purely silicon based solar cells, which did not have a significant development in efficiency in the last few decades. My project targets the issues of its commercialization, which is mainly that it contains lead, and it can contaminate the natural environment when a failure in the cell happens. To prevent this, I was developing new solar cell materials from ammonium phosphates, which are known to be effective against lead contamination.

6. 50- to 75-word abstract of your project:

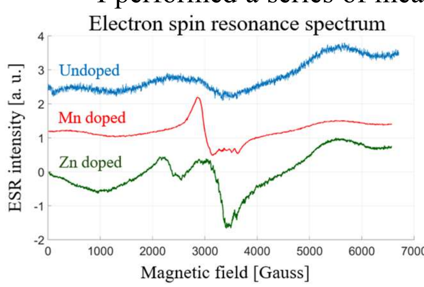
Perovskite-based solar cells are among the most promising emerging photovoltaic technologies. However, their commercialization faces challenges, mainly because the perovskite material contains lead and is water-soluble. If the cells are damaged, the lead from the perovskite can leach into the soil. The project aims to address this issue by using ammonium phosphates, which are commonly employed in industry to capture lead, as charge transport layers in solar cells.

7. References for papers, posters, or presentations of your research:

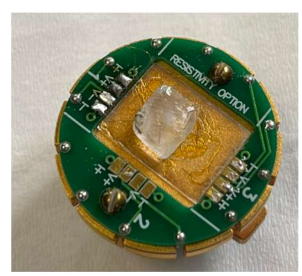
Silicon-based solar cells are widely used in commercial applications, but they have limitations, such as being expensive and having a stagnant efficiency over the past few decades. One solution to improve the commercialization of solar cells is to use perovskite based (PSC), or perovskite-silicon tandem solar cells. However, all the effective PSC-s contain lead at the B site in the ABX_3 molecular structure. Perovskites are sensitive to water[1] too, so if there is a fatal damage, and water enters the active region, perovskite will be dissolved, and lead can escape to the nature. Ammonium phosphates are widely used in industrial applications to prevent Pb leaching. The thin film solar cell architecture includes electron and hole transport layers for charge separation among the perovskite active layer, and one of them needs to be transparent to let the light reach the perovskite layer for charge carrier generation. Besides that, these layers need to be conductive, and they should only be conducting one of the charge carriers to prevent fast recombination The idea of the project was to use these phosphates as a charge transport layer.

Ammonium phosphates are insulators, but a fairly good conductivity (in the region of 10^{-6} to 10^{-3} S/cm) is necessary for our purposes. Therefore, I used chemical doping with different metals, such as zinc, manganese, and tin to improve conductivity. From a water-based solution I grew single crystals, and with a precipitation process I made a nanocrystalline colloid solutions for thin film fabrication development.

I performed a series of measurements learnt during the program to study doping and the physical properties of samples. Electron spin resonance spectroscopy, i.e., is sensitive to the electric and magnetic properties of the electrons with unpaired spins in the material. By comparing the ESR spectra of the pristine and doped materials, it can be concluded that the doping was successful. I used x-ray diffraction and Raman spectroscopy measurement of powder samples to determine the crystalline phases, which turned out to be mono (MAP) and diammonium-phosphates (DAP). I tried using a spin coating to develop thin films from these solutions, but I discovered that a solution-based process is unsuitable for phosphates. Therefore, I developed a titanium-dioxide-based spin coating method. TiO_2 is a commonly used charge transport material in solar cells. I was able to spin-coat transparent films after the separation of the nanocrystallines by size.



To characterize the electric conductivity of the previously mentioned single crystals, I tried using DC methods; I discovered that the resistivity depended on time and applied voltage, so instead of this method, I turned to high-frequency impedance spectroscopy techniques, and the measurements are in progress.



In conclusion, the doping of ammonium phosphates with different metals was successful, and there is a promise for achieving effective conductivity, but measuring the resistance of these single crystals is a complex challenge that should be evaluated in the future. The analysis of the thin-layer phosphates TiO_2 composites showed a high TiO_2 content that should be reduced in order to harness the lead-capturing property of phosphates.

[1] Fighting Health Hazards in Lead Halide Perovskite Optoelectronic Devices with Transparent Phosphate Salts | ACS Applied Materials & Interfaces