

Summer 1 Reflection Blog

As my research project period comes to an end, it is time to reflect on the project itself and its various findings, as well as the numerous lessons I have learnt over the last 6 weeks. It has been an unbelievable journey that has broadened my knowledge of renewable energy and solar panels, as well as opened doors to other realms of engineering such as nanoscience and material engineering. However, it has also taught me valuable skills regarding research and independently led tasks that I will be able to apply throughout the rest of my life.

My overall goal for this project was to identify how nanomaterials could help Perovskite Solar Cells (PSCs) become a bigger player in the solar energy industry by addressing key issues such as increased efficiency, stability and durability, and help the cells become mass-produced. Furthermore, I wanted to identify if these materials could help resolve environmental issues associated with PSCs such as lead leakage. By finding nanomaterials that were easy to source and fabricate, implementable in the cells, and capable of solving these problems, a clear solution could be uncovered and help assist manufacturers and researchers in their journey of making PSCs competitive against silicon-based solar cells.

I initially began this project by conducting base research on the structure of PSCs, existing manufacturing methods, environmental issues associated with the cells, as well as which nanomaterials have already been used in PSCs. This allowed me to clearly understand how these cells work, as well as the challenges they are facing that has restricted their widespread application commercially and residentially. This research also showed me applications of nanomaterials throughout the cell's various layers, such as the electron transporting layers, electrodes, and the perovskite active layer itself. I chose to focus on the use of nanomaterials in the active layer because it provides the opportunity to enhance the energy extraction and conversion abilities of the cell, as well as improve the quality of the active layer itself. From here, I chose 3 existing nanomaterials that had evidence of being incorporated into the active layer as my area of interest for the project. These materials include titanium dioxide, carbon-based nanomaterials such as carbon nanotubes (CNTs), carbon quantum dots (CQDs), and graphene, and MXene materials such as titanium carbide and vanadium carbide. These materials were selected based on the available literature where they were used as additives in the active layer and results were provided, as well as the complexity of their chemical structures. I then conducted another literature review on the selected materials to further understand their chemical structures as well as their chemical, electrical and mechanical properties.

Using the conducted literature reviews and established background knowledge, I then set off to conduct my analysis on how these materials can help enhance the capabilities of PSCs. Using previously conducted experiments and laboratory-constructed PSCs, I analysed and compared 60 PSCs in terms of efficiency, and stability and durability. The efficiency of the cells was determined by extracting key results from the studies, such as Power Conversion Efficiency (PCE), Short Current Density, Fill Factor and Outer Circuit Voltage. Using tools such as Microsoft Excel, an average for each characteristic for each nanomaterial additive respectively was calculated and represented graphically. In terms of stability and durability, the cells were compared based on their testing conditions, such as exposure to solar radiation, humidity and temperature. The results proved to be extremely interesting, and helped unpack how the nanomaterials' characteristics could help enhance or dampen perovskite's existing

properties. What was found was that MXene materials such as titanium carbide and vanadium carbide helped the cells achieve the highest average efficiency of the sample group, as well as improve the cell's stability in various conditions. Carbon-based materials such as graphene, CNTs and CQDs also showed promising results, particularly when exposed to extremely harsh relative humidity levels. The worst performing material proved to be titanium dioxide, which had the lowest efficiency results and poor stability and durability outputs of all the cells studied. Through extended research, I concluded that the use of this nanomaterial would be better suited in the electron transport layers as opposed to the active layer.

I then analysed the materials from a manufacturing perspective. I investigated the average cost to fabricate the materials and the ease at which they could be incorporated into existing PSC manufacturing processes. This is an important aspect to look at because if the material was shown to be expensive and difficult to work with, its use on a mass-scale would not be investigated further by PSC companies. To do this, I calculated a price per milligram to use each additive using existing commercially available products manufactured by suppliers such as Merck, ACS Materials, and Nanografi. Furthermore, I analysed the scientific methods of the studied cells to understand how they were being integrated into the active layer on a laboratory scale, and if this could be translated into an industrial scale. While I found that all of the materials could easily be incorporated into the active layer, and were even compatible with methods such as slot-die casting and Roll-to-Roll Manufacturing, MXene was shown to be the most expensive material owing to its costly base materials and complex synthesis methods. On the other hand, Graphene and CNTs were shown to be the most cost-effective materials.

Lastly, I looked at the environmental impact of each of these nanomaterials by analysing their life cycle assessments in existing literature, as well as the material's ability to address the issue of lead leakage in the active layer. While I found that all of the materials have sustainability disadvantages such as extensive greenhouse gas emissions, use of toxicity solvents or catalysts, and poor recyclability, more research is being conducted into the creation of 'green' nanomaterials, showing signs of improvement for future uses. Furthermore, MXene materials, CNTs and CQDs all showed to reduce the occurrence of lead leakage within the active layer, which helps decrease the overall environmental impact of the cell itself.

Although this research showed me that there is still an extensive amount of research and development required to make these nanomaterial additives eliminate all of PSCs' current issues, it has also shown the unbelievable advantages and benefits its usage has on PSC's performance. This space has a huge amount of potential for growth and expansion, assisting PSC's in their efforts to become one of solar's leading products.

This research project has been an amazing experience and has allowed me to grow in so many different ways. I have always been passionate about renewable energy, and in particular solar energy. Therefore, the opportunity to expand my knowledge on the topic and to see its intersectionality with other emerging engineering technologies such as nanomaterials has been fascinating and something I will take through into my studies and career. Furthermore, this project has allowed me to improve my researching skills such as developing and writing literature reviews, analysing and comprehending extensive experimental data, and discussing my findings in academic-style writing. One of the main challenges I experienced was time management. This was because when I initially started my project, I was overly ambitious and

underestimated the amount of time I had for the project versus the depth in which I wanted to research each section and material. This meant that I had to go back to the drawing board multiple times to re-evaluate the aim of my project and what I wanted to achieve.

This project has not only given me the opportunity to discover so much more about Perovskite Solar Cells and nanomaterials, but it has also allowed me to deepen my understanding of engineering terminology and skills I have learnt over the last few years of my degree. I was extremely lucky to be able to work alongside leading academics in the field, such as Dr Amir Pakdel. Not only did Dr Pakdel help and guide me throughout the project, but he also helped me refine my research topic and improve key skills such as academic writing and presentation. Overall, I have loved every minute of this research project and look forward to continuing to work on this topic in the future.