BEng Renewable Energy Engineering

Design of a Refractive Optical Element as a Spectrum-Splitting Solar Concentrator for Lateral Multi-Junction PV Cell Collection

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Introduction

With the ever-increasing advancements in energy production systems, solar panels on the market have experienced relatively low efficiency increases at 9% over 60-70 years (NREL. 2020). Single junction cells only absorb solar irradiance in one bandgap which does not cover the whole spectral irradiance that the sun produces. Exploring this further, research presents methods which scientists have undertaken to increase efficiencies in Photovoltaics (PV) systems, using multiple junction in one cell. Current records for a six-junction PV cell stands at 47.1% efficiency (NREL. 2020).

Multiple junctions enable the PV cell to absorb more of the spectral irradiance from the sun. Figure 1 shows a 4 junction PV cell which is able to absorb the colours, shown in Figure 2, blue, green, yellow, and red. The greyed out area in Figure 2 is all that the single junction Silicon PV cell can absorb. This clearly shows more junctions result in an increased spectral absorption.

The problem

The solar industry to date, has been unable to produce a viable multi-junction solar panel to market. There are many reasons for this, for instance, lattice and spectral matching between each junction, and the complex, expensive fabrication used to manufacture vertical multi-junction (metal organic chemical vapour deposition, wafer bonding, and epitaxial growth) (Thio, S.K. and S. Park, 2019) (Huang, Q. et al, 2013). Therefore a solution is needed that avoids these barriers to market.

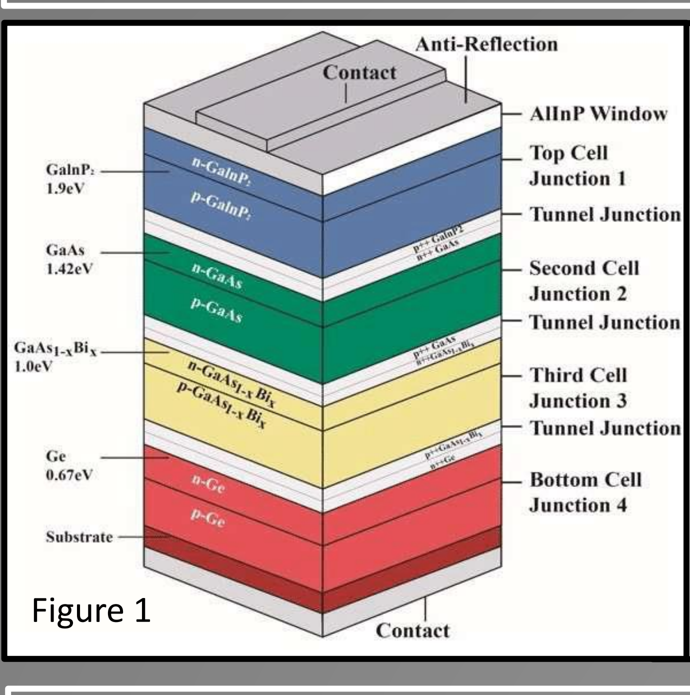


Figure 1

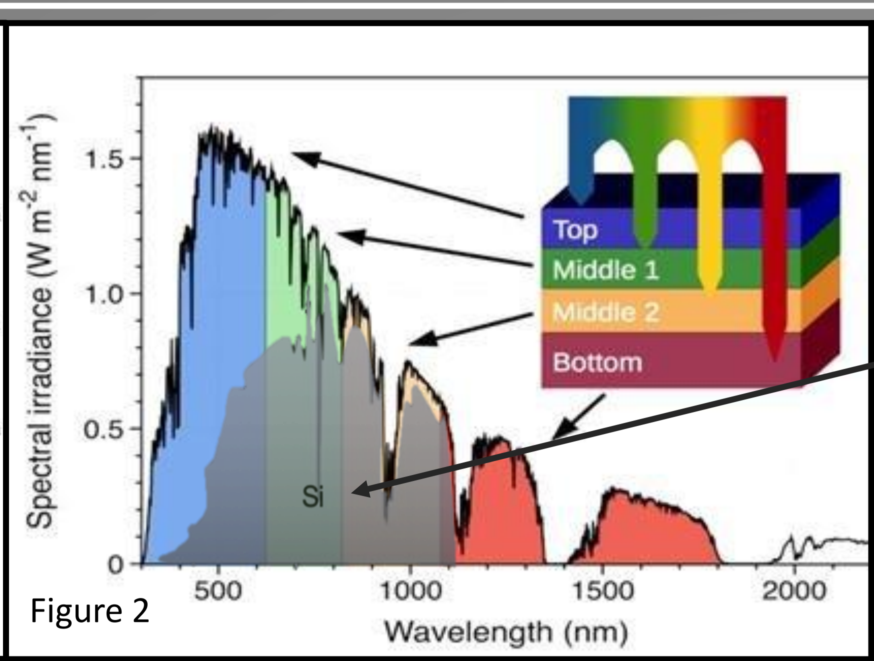


Figure 2

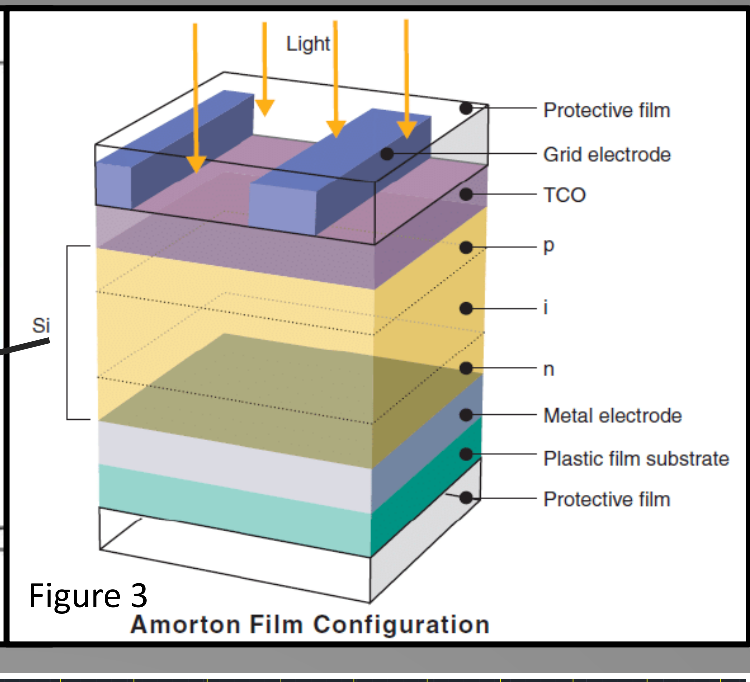


Figure 3

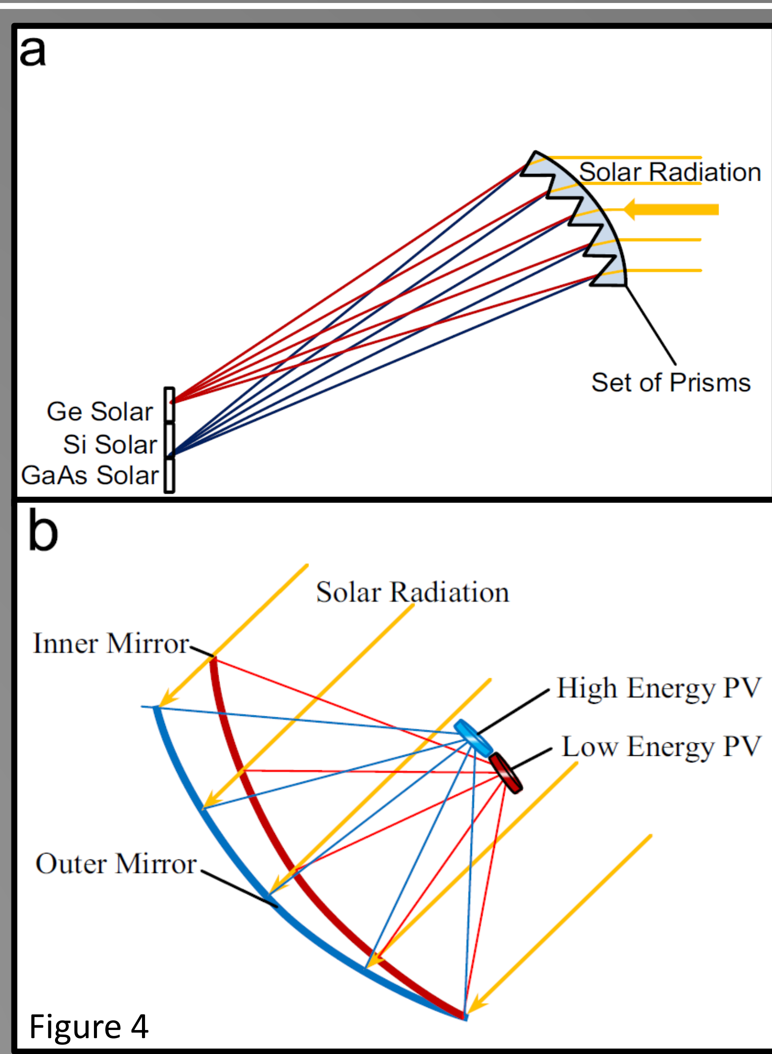
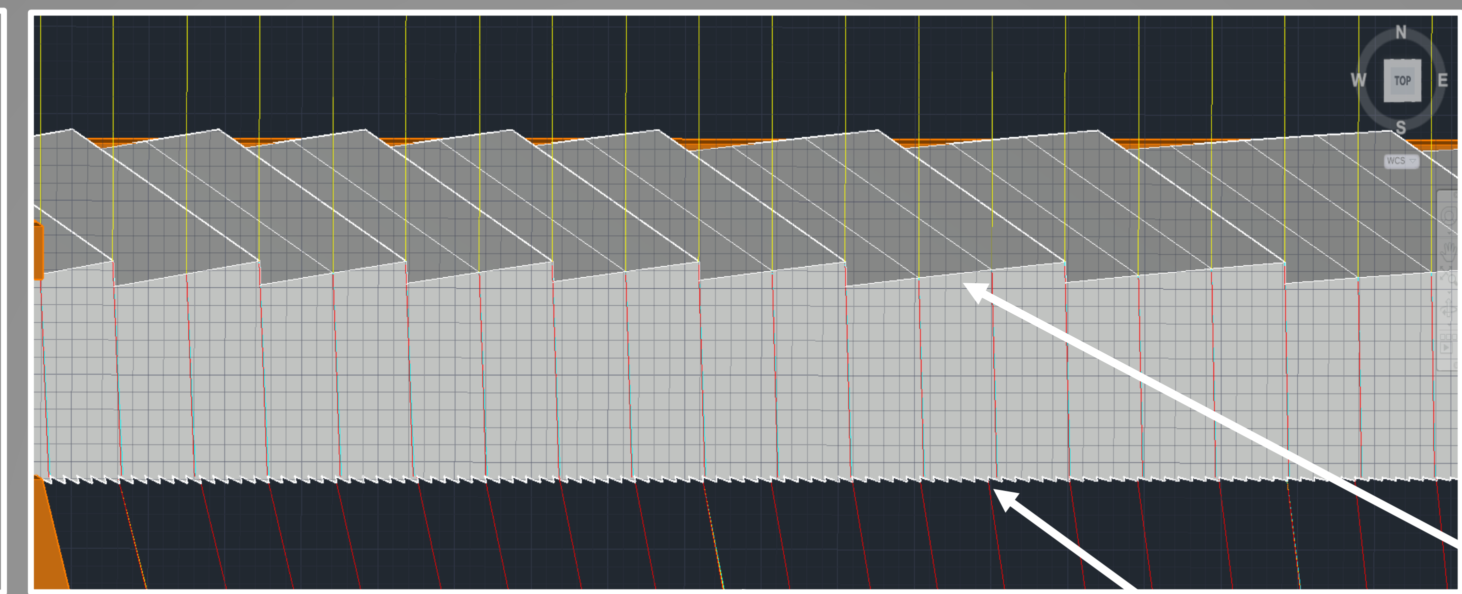


Figure 4

Aims & Objectives

- The aim of this project is to research, design and compare a PV system that has an alternative approach to vertical multi-junctions.
- The objectives are to use existing theories, research and technology to find the optimal method for concentrating and splitting solar irradiance for lateral multi-junction design.
- Using research, design the full system to have a high efficiency and keep the complexity of the design low.



Solution

Many different designs were investigated, having different advantages and disadvantages. An effective design, research presented, was a lateral multi-junction approach. This design places different junctions adjacent one another instead of on top of each other shown in Figure 1. The light is simultaneously split into the wave spectrum, allowing that split light to fall onto the appropriate PV cells, and concentrated to reduce current losses (Zheng et al. 2019). This could be achieved using a lens based system or a mirror based design as shown in Figure 4. The lens based design was selected for this project, because of better optical efficiencies, cheaper raw materials (compared to dielectric mirrors) and it avoids many of the main barriers to market that vertical multi-junction's face.

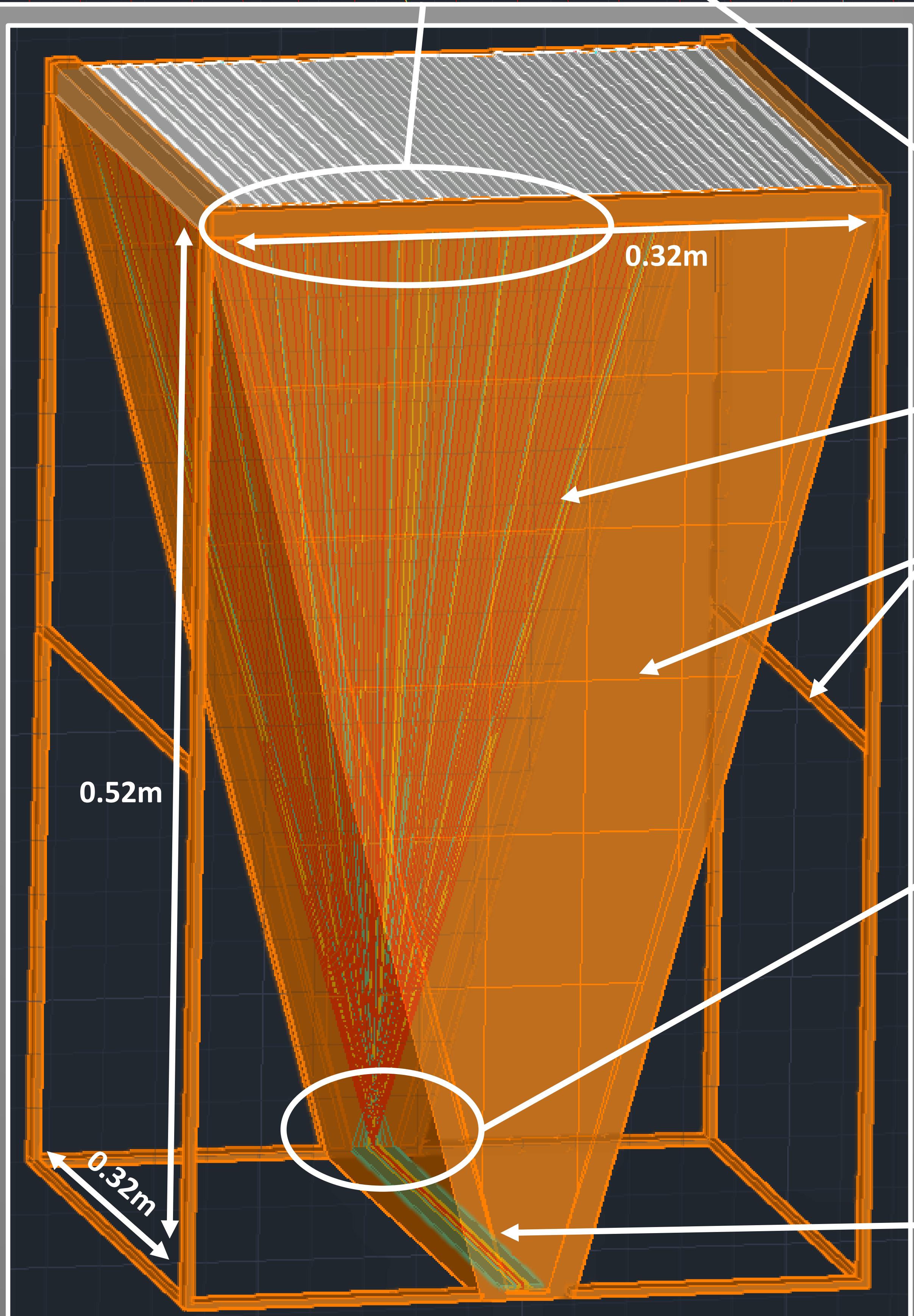
Using a lens based design manipulates the solar irradiance using refraction. The laws of refraction are relatively simple allowing the project to be designed in Excel and AutoCAD.

Advantages

- Avoids the main barriers that vertical multi-junctions face.
- Concentrates solar irradiance reducing current losses.
- Splits light which reduces thermalisation losses on the cells.
- Increases the amount of power that can be produced in comparison to a single junction PV cell.
- Flexible choice in PV cell selection.
- Low optical losses.
- Replaces expensive and complex components with cheaper less complex ones.
- Reduces the size of PV cells with concentrated light.

Disadvantages

- Small acceptance angle means solar tracking is required.
- Solar tracking reduces overall power output.
- The dimensions of the module and solar tracking reduces the application of this system.
- Maintenance may need to be more frequent.



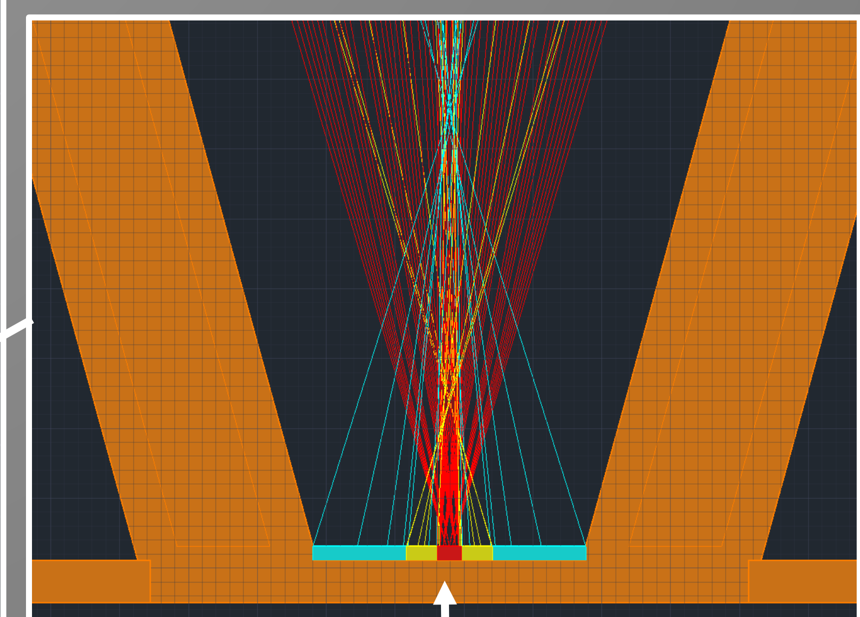
Design Labels

The curved prisms are used to disperse and concentrate solar irradiance. They are exposed to the elements so are larger than the exit prisms below, making maintenance easier.

Exit prisms are used to direct the light that has entered the lens towards to PV cells, and further disperse the solar irradiance into the wave spectrum. Each of the 176 exit prisms had to have their angles individually calculated, drawn, checked and mirrored to produce the whole lens.

By raytracing using Excel, the solar irradiance is tracked through the lens, as it is refracted towards the PV cells. This was repeated for the varying wavelengths, as each wavelength refracts slightly differently allowing the light to be dispersed.

The stand keeps the module upright, and the module's case protects the PV cells and exit prisms from the elements.



The solar irradiance is concentrated and split along the rectangular PV cell (line focus). The two blue PV cells are for the Ultraviolet light. The two yellow PV cells are for the visible spectrum and the red PV cell is for the Infrared spectrum.

Results & Implications

The Lateral multi-junction was designed using AutoCAD and later tested by raytracing the light through the lens. The project found that light could be split and concentrated. 85% of the solar irradiance was incident on the correct PV cell and a range of concentrations of suns was produced from 22-84. The overall efficiency of the system was found to be 30.8%, and produced a maximum power, in theory, of 444W when covering the same area as a standard PV panel.

With the configuration and PV cell selection chosen, there was an increased efficiency of 8%, compared to the current market. As expensive and complex processes are avoided in this multi-junction design, it gives more companies access to solar technology. This allows more people access to renewables, decreasing the demand and reliance on fossil fuels and therefore reducing greenhouse emissions.

Conclusion

The project successfully found a viable alternative multi-junction approach, which was designed and tested in theory. It was shown to be highly efficient, low complexity, and avoids the main barriers to market that vertical multi-junction have faced.

References

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