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| Project Name | Small pyramids for Light trapping in silicon solar cells |
| Mentor and Faculty PI | Stuart Bowden , Som Dahal (Raymonnd Tsui, Trevor Thornton) |
| Project Summary | A solar cell is a device that changes sun light into electricity. For a solar cell to be effective and efficient, it is necessary that most of the sun light be absorbed in the device without reflection. As polished silicon has 40% reflection, surface texturing reduces the reflection down to 10% as well as enhances the path length of light so that the probability of absorption of photons in silicon increases. Current commercial silicon solar cells have upright pyramids of size 5-10 μm on the front surface to reduce reflection of light. But the silicon surface with smaller (~1 μm) sized pyramids has the same reflectance (~10%) as larger pyramid sized surfaces. With the same reflectance as larger sized pyramid surfaces, smaller pyramid surfaces have not only the potential of having higher open circuit voltage due to better surface passivation but are also required for silicon based tandem devices where the top layer has to be deposited by spin coating. Together with the above mentioned benefits, the smaller sized pyramids on the surfaces are also beneficial for certain contact printing technologies such as aerosol printing and ink jet printing.<br>The small pyramid fabrication project is an attempt to create small, uniform sized pyramids on the crystalline silicon wafer surface. Surface texturing with anisotropic etching in potassium hydroxide (KOH) will be used for this project. The size and uniformity of these pyramids can be tuned with texturing chemistry and texturing time. For example higher concentration of surfactant (150 ml GP Solar Alkatex zero) and a shorter time etching (5 minutes) results in a pyramid size of about 600-1000 nm. All processing conditions will require thorough characterization to produce relevant statistics for size and uniformity control. In this project, we will study the effect of surface texturing chemistry and texturing time on the size of pyramids on n-type wafers and design the experimental processes to achieve smaller sized pyramids. We will be using scanning electron microscope (SEM) to investigate the size and uniformity of the pyramids. If time permits, we will compare the 3D images obtained from SEM with the images obtained from AFM. We will study the potential improvements in the solar cells efficiency by studying the surface passivation of these wafers by analyzing the minority carrier lifetime after deposition of surface passivation layers such as amorphous silicon. For this study we will use n-type wafers. |
| REU Work Plan | 1. Students will familiarize themselves with the silicon surface texturing process and related chemistry<br>2. Students will design and run the experiments based on the information in the literature provided and the guidance of the mentor.<br>3. They will work with the mentors and other students in the lab to characterize the pyramid shape and size with Scanning Electron Microscope (SEM). For this students will go through the SEM training.<br>4. The students will design and implement the process flows to control pyramid size with KOH texturing and characterize the structures. |

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| | 5. They will perform comparative analysis with reflectance measurement between the different pyramid size silicon surfaces and correlate those with the pyramid size obtained from the texturing process.<br>6. Students will perform the surface passivation of the silicon surface by coating the surfaces with intrinsic amorphous silicon, i-a:Si(H), and correlate the minority carrier lifetime to the pyramid sizes and texturing conditions |
| Desired Technical Output | The students should be able to describe the impact of texturing chemistry and time on the pyramid size and the effect of pyramid size on solar cell performance and identify avenues for improving solar cell parameters such as open circuit voltage, short circuit current and efficiency. Fabrication of solar cells from the samples of different pyramid size and comparison of solar cells electrical parameters and correlating them with the pyramid size would be a plus. |
| Risks and Mitigations | 1. SEM related Issues -> Currently, SEM is down in SPL and due to vacuum and other related issue, Students have to use SEM in campus in Prof. Thornton's lab<br>2. Micro Vs Nano -> Although this is a "nano" project the pyramids are (in their smallest scale) to few hundred nanometers.<br>3. Surface passivation and solar cell fabrication -> As this project is focused on N-type wafers, we intend to make silicon heterojunction (SHJ) solar cells. This includes the extensive use of PECVD for a-Si(H) deposition and sputtering tool for ITO and silver deposition. The availability of the tools and operators might be an issue |
| Equipment/consumables not in hand | ➢ For AFM analysis of pyramid size in SPL, the equipment is not fully 'up' yet but we are working on it. AFM on campus might be needed |
| Publication Opportunities | Poster for the 2017 silicon workshop and possible later journal publications. |

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| Project Name | Atomic Force Microscopy and Time Resolved PL (AFM&TRPL) |
| PI and Mentor | Richard King, Abhinav Chikhalkar |
| Project Summary | $Cu(In,Ga)Se_2$ and CdTe compound semiconductors are among the most promising materials for development of scalable low-cost high-efficiency flat-plate tandem solar cells. The low bandgap compositions of these material systems have seen a steep increase in efficiency in the past few years because of the development of novel post deposition treatments (PDTs) – which are predicted to passivate the grain boundaries and reduce losses due to defects. Development of these material system for high bandgap top cell is an area of active research. Therefore, it is important to develop an understanding of the defects'/ grain boundaries' role as they relate to device performance.<br>This project will develop our understanding of the effect PDT has on the electronic properties of grain boundaries in low bandgap materials and eventually correlate it to the overall performance of the cell. Effect of Mg/Zn addition in CdTe on its grain boundary conductivity/ potential will be explored to answer the question "How can we develop better high bandgap polycrystalline solar cell?" |
| REU Work Plan | 1. Students will develop a basic understanding of semiconductor defect physics to address questions in compound semiconductor solar cells<br>2. Students will be encouraged to design a plan and probable correlations to expect by carrying out a set of characterizations<br>3. Students will be given hands-on experience to probe the properties of grain boundaries using conductive AFM, surface potential measurements, time resolved photo-luminescence (probable), Hall measurement (probable) and solar cell efficiency measurements (I-V) |
| Desired Technical Output | The students will learn various techniques to probe defect characteristics in a semiconductor. They will also develop a better understanding of the effect defects have on solar cell performance<br>The overall goal is to understand and develop subcell materials for multijunction solar cells. By developing an understanding of how the defect characteristics are changing either by addition of newer elements or post deposition treatments, we are one step closer to controlling the defects to our requirements. |
| Risks and Mitigations | 1. The samples could be too rough to carry out AFM study (roughness < approx. 200nm needed)<br>2. The TRPL detector might not be sensitive to these band gaps (low response for bandgaps between ~1.24 eV and ~1.38eV |
| Equipment/consumables not in hand | A set of CdTe samples with/ without PDT, and with various Mg/Zn concentrations would be needed (with and without a device being made) is currently no in hand. These will arrive next week from our partners at University of Colorado. |
| Publication Opportunities | Where are you planning on publishing the work on the bigger project?<br>If the measurement techniques work for this application there is the potential to publish for a conference paper about the measurement and a journal article about the results. |

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| Project Name | Nanoparticle rear reflector for Al contacted SHJ solar cells |
| PI and Mentor | Zak and Jonathan |
| Project Summary | Replacing the ITO/Ag stack at the back of SHJ solar cells with Al could reduce module costs if there is no degradation in performance. We are currently working on developing an Al rear contact that employs a nanoparticle rear reflector/Al contact combination. This project will determine what the best nanoparticle layer combinations result in the highest long wavelength reflection and if these result in enhanced current collection in SHJ solar cells. |
| REU Work Plan | 1. Create an optical model in CompleteEase software of nanoparticle layers that result in the highest reflectance at 1200 nm<br>2. Create recipes to fabricate layers with the modelled optical properties<br>3. Deposit the layers and characterize them<br>4. Determine if they had the desired characteristics and if the model is valid<br>5. Make a batch of solar cells with the best layers and determine if there is a performance improvement over control samples |
| Desired Technical Output | Nanoparticle films have never been shown to improve solar cell performance. Developing an optical model that can be used to develop nanoparticle recipes for enhanced light trapping with be a great contribution to our ongoing efforts to achieve this goal. Developing a nanoparticle rear reflector that improves solar cell performance will be a world first. |
| Risks and Mitigations | I don't think there are any. This is basically continuing where Kari left off and there has been very little down time of related tools. Getting to the point of making cells might be too ambitious but like I said above it won't really matter. Can you think of anything that could be an issue? |
| Equipment/consumables not in hand | We forgot to discuss this – is there anything of concern here? |
| Publication Opportunities | Someone to fill in |

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| Project Name | Determining dopant concentrations in a-Si layers for SHJ solar cells |
| PI and Mentor | Zak and Will |
| Project Summary | Contact resistance in SHJ solar cells is determined by the active dopant densities in the a-Si layers. Doping densities in a-Si layers is hard to measure. We know contact resistance as a function of gas flow but don't know the relationship between gas flow and doping density or the effect of active and inactive dopants on solar cell performance. In this project we will try to develop a (novel) method to measure the active dopant concentration in doped a-Si layer. |
| REU Work Plan | 1. Students will learn how solar cell efficiency changes with the active dopant density in the doped a-Si layers using "afors-HET" software<br>2. They will design an experiment to vary the dopant density in these layers and get the samples made<br>3. They will participate in SIMS measurements of the samples to measure the atomic dopant density<br>4. They will make measurements with Hall Effect and dark conductivity measurements and characterize the active dopant density<br>5. They will correlate these results with contact resistance measurements and verify the model<br>6. They will help make a batch of solar cells with several doped a-Si layers and measure the impact of doping density on solar cell performance |
| Desired Technical Output | 1. Combining different methods of determining dopant density will allow us to compare different techniques.<br>2. If Hall Effect 'works' we can utilize this much faster method.<br>3. By measuring inactive and active dopants we can determine the effect defects have on solar cell output |
| Risks and Mitigations | 1. SIMS will take time to get trained on and may not yield very accurate results. It is also sometimes heavily booked<br>2. The Hall Effect measurement technique might not work. Finding out either way will be valuable information but may not feel like a "success" |
| Equipment/consumables not in hand | May need some assistance in lithography for later experiments. |
| Publication Opportunities | Potential for co-authorship on journal publication. |

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| **Project Name** | Surface recombination and bulk lifetime (SRV) |
| **PI and Mentor** | Mariana and Simone |
| **Project Summary** | The global goal of solar cell research is to increase cell efficiency and reduce (or at least not increase) costs. High efficiency solar cells generally incorporate high lifetime wafers and as cell architecture moves in this direction surface passivation stability becomes more and more important. The surface recombination velocity (SRV) associated with high lifetime wafers passivated with various thin film materials has been shown to increase over time and degrade module output. In this project we use an in-house model to determine the initial SRV of various materials on different types of wafers and make a start on accelerated lifetime testing to determine how their stability will impact their long term performance. |
| **REU Work Plan** | 1. Students will learn the basic knowledge about solar cells and losses associated with recombination mechanisms<br>2. They will design an experiment to access the information relative to the c-Si/passivation layer interface<br>3. They will assist their mentor in sample preparation<br>4. Characterization of passivation layers and interface defects<br>5. Extrapolation of bulk lifetime and comparison with previous reports |
| **Desired Technical Output** | The students will learn how the overall performance of a PV device is influenced by SRV and which are the best conditions for operation. They will contribute to the comparison of the most relevant dielectric layers used for passivation and to evaluate their ideal working range. |
| **Risks and Mitigations** | 1. Work integration for two students and similar work load → careful planning ahead of their activities<br>2. SPL facility busy or P5000 down → optimization of $SiO_2$ deposition with the Angstrom tool in DEfECT lab |
| **Equipment/consumables not in hand** | Is there anything we need to order/prep beforehand?<br>*We have everything we need for this project* |
| **Publication Opportunities** | Reports on SRV characterization were published in conference proceedings and scientific journals. This work will be part of a broader project of great interest in the field. |