Design of new material solar cell and analysis of efficiency, cost and resource availability.

Client & advisor: Vikram Dalal

Team: SdDec24-21

URL: https://sddec24-21.sd.ece.iastate.edu

Our Team

Payton Bills:

Team Lead

Device Fabrication

Anders Peterson:

Component Design

Device Fabrication

Drew Jensen:

Fabrication Design

Device Testing

Michael Thomas:

Fabrication Design

Device Testing

Jonathan Timm:

Economic Analysis

Material Viability

Jacob Steffens:

Economic Analysis

Material Viability

Background

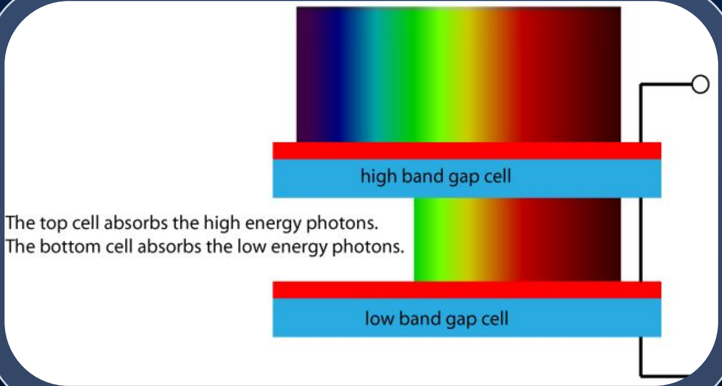
Problem Statement:

- Typical solar cells are a semiconductor made of silicon, and convert light into electricity.
- Silicon cells are approaching their theoretical efficiency limit. (~30%)

Background

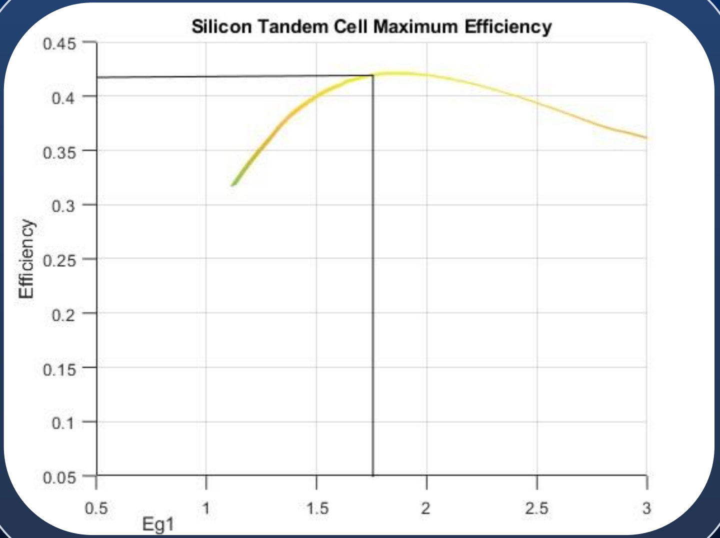
Solution:

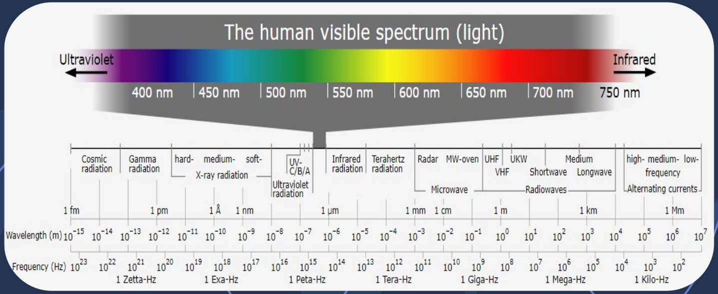
- One way to increase commercial efficiency past this point is to add a second solar cell on top made of a different material.
- Our project is to develop a CdSe-Si tandem cell
- This would benefit a wide range of users from utility companies to local residents



Background

- Key concepts:
  - Semiconductors absorb light efficiently in certain ranges of light spectrum
  - Energy lower than the band gap will pass through the material
  - Tandem cells have an ideal band gap pairing for ideal efficiencies
- CdSe absorbs higher energy light more efficiently than Silicon.
  - Silicon | Eg = 1.12 eV
  - CdSe | Eg = 1.74eV





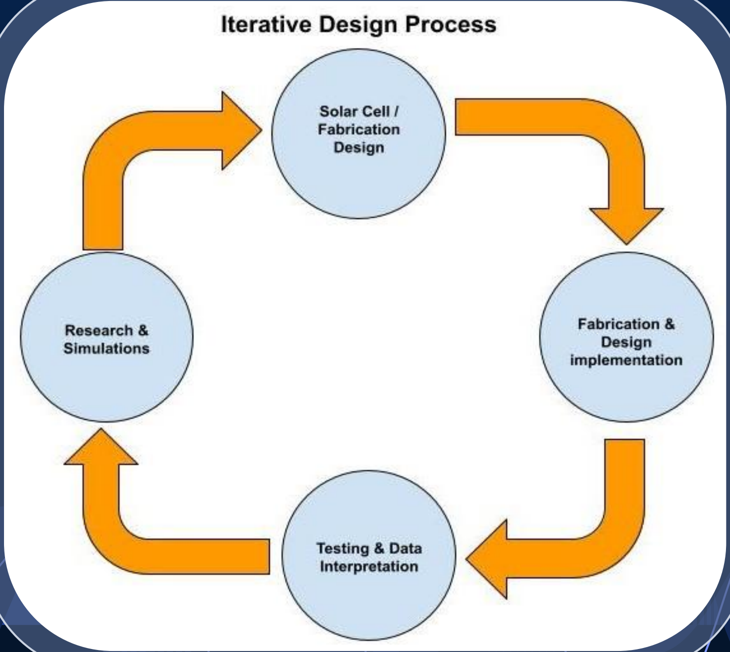
Project Plan

Spring Semester: (CdSe only)

1. Identify the problem (Background)
2. Potential Solutions / Semiconductor Materials (Overview)
3. Break the project down into two major parts:
   - Fabrication & Testing Process Design
   - Economic Feasibility & Environmental Viability

Fall Semester: (Silicon tandem cell introduced)

1. CdSe-Si presented a unique challenge, involving research not conducted since the 1980s
2. Required more research before fabrication could begin, as well as more total fabrication time
3. Training: Lab Safety, Fabrication, Measurement
4. Potential Silicon + Tandem Cell Solutions / Semiconductor Materials
5. Fabrication of silicon, then CdSe tandem cell
6. Economic analysis & research environmental viability
7. Reports on findings and secure fabricated cells



Technical Requirements

- Achieve separately functioning CdSe and Si solar cells
  - Exponential I vs V curves (Large Fill Factor)
  - V_{oc} ~ 0.5V for Si and ~0.8V for CdSe
- Achieve a tandem V_{oc} ~ 1.2V
- Economic and sustainability analysis to assess the viability of tandem cell implementation

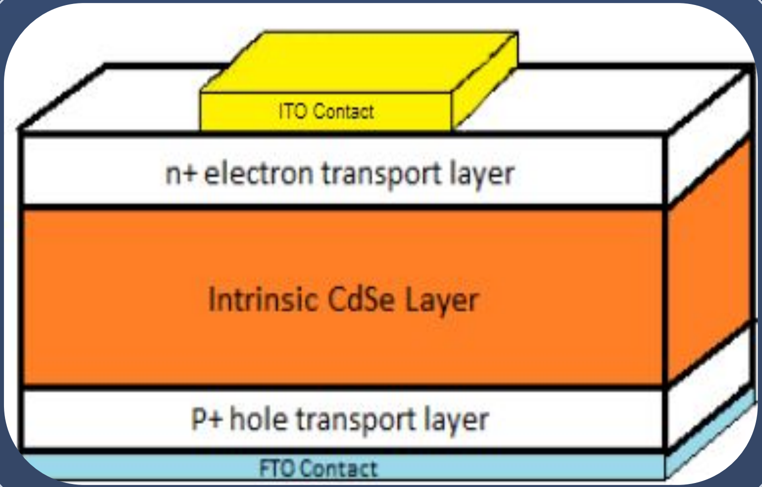
Design Overview - Cell Design and choice of materials:

In general solar cells have:

- P-N junction
- Conductive contacts

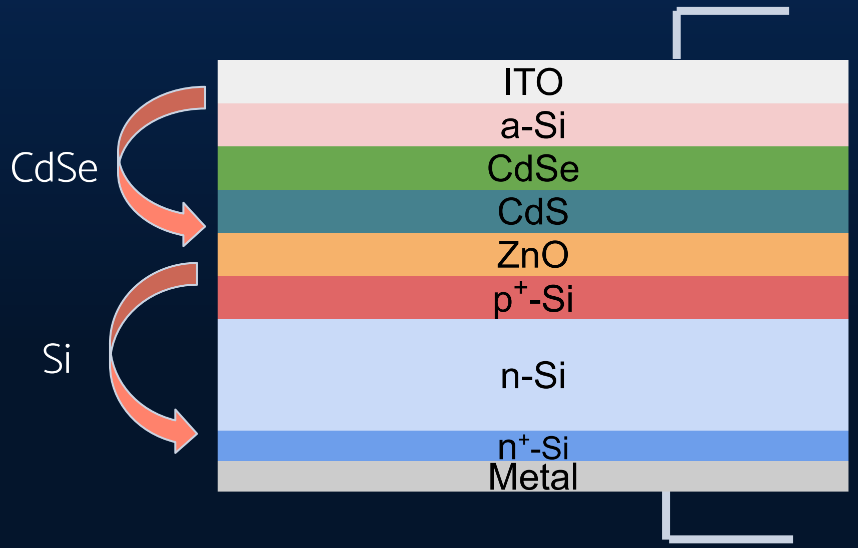
These components are carefully chosen based of material properties:

- Material Interfaces
- Relative energy levels
- Material Thickness

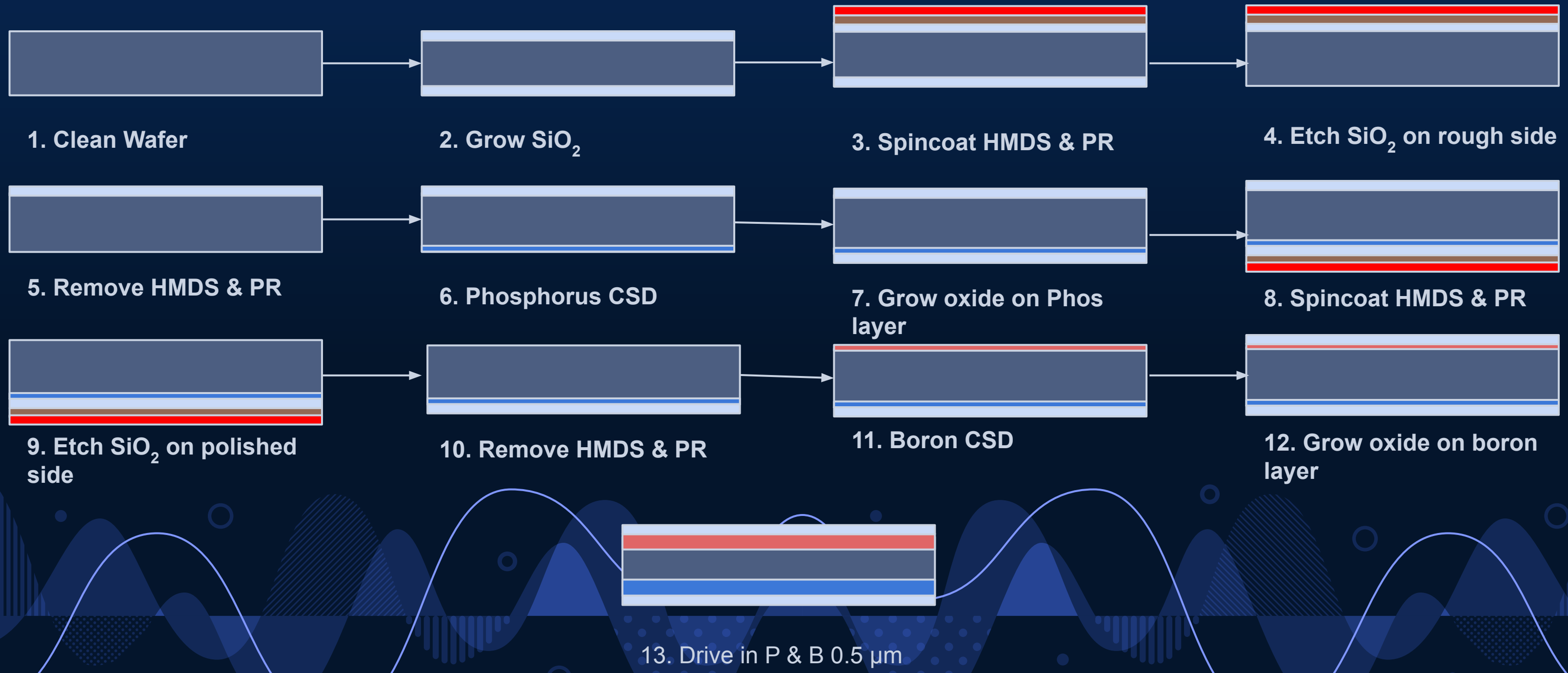


Design Overview - New Device Design

- This semester, we have switched design goals to fabricate a tandem cell rather than focusing on CdSe
- New fabrication process was developed to add the Si bottom cell



Design Overview - Silicon Cell Process



Si Wafer Cleaning

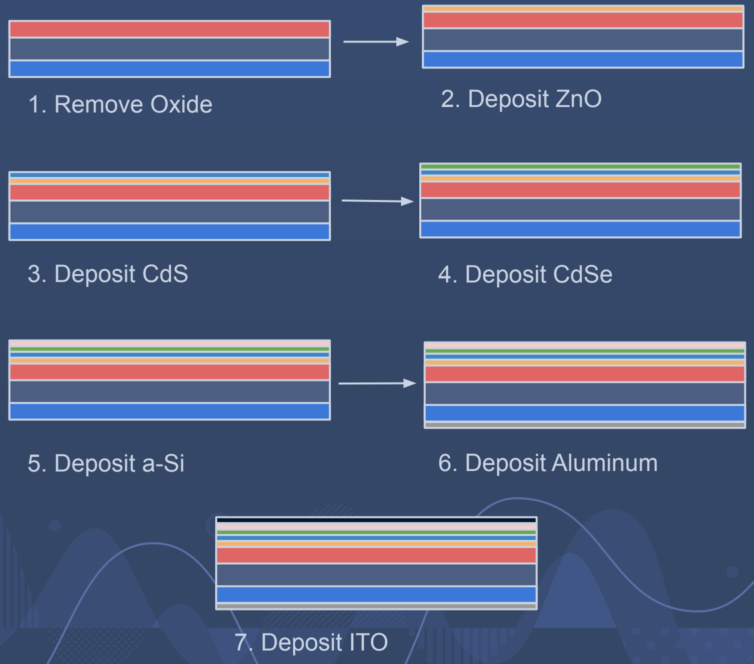
Phosphorus Doping

Boron Doping

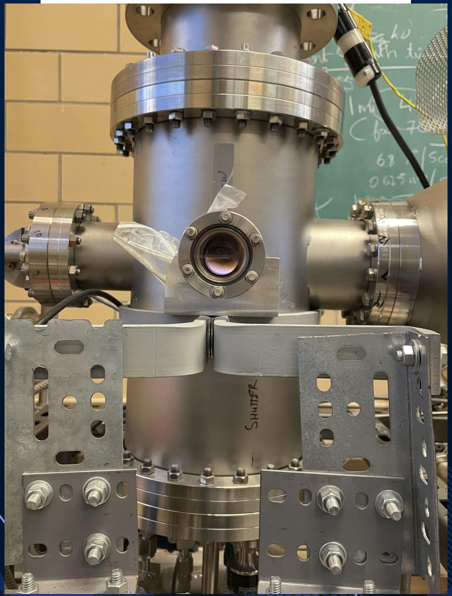
Si Cell with Al Back Contact

Si Cell with ZnO Top Contact

Design Overview - CdSe on Si Process



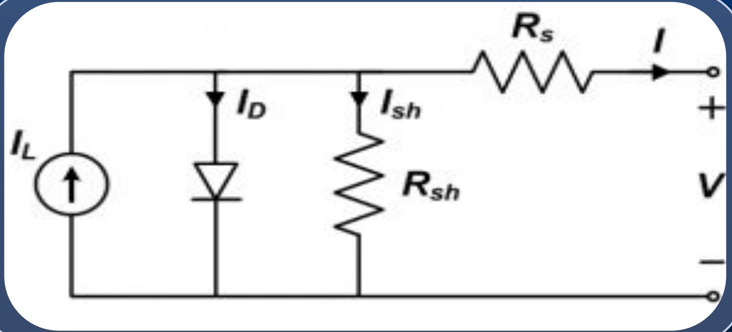
Sputtering Chamber

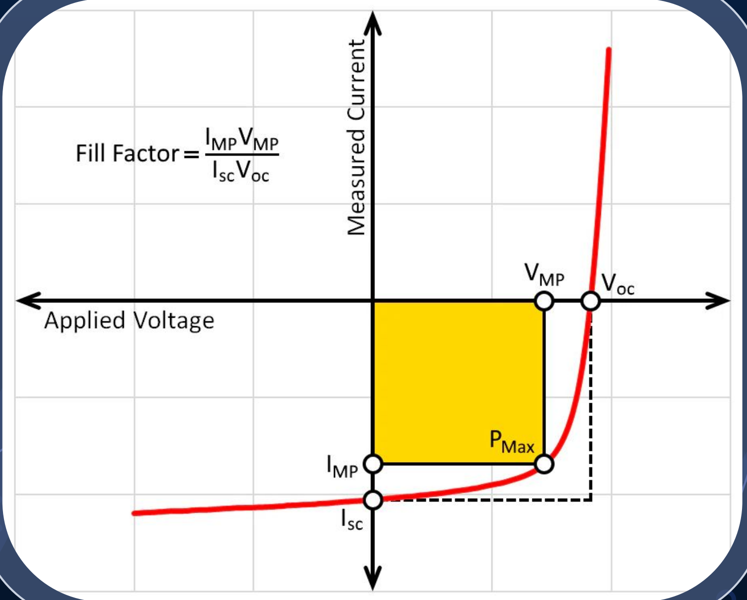


CdS/CdSe Evaporation Chamber

Solar Cell Model

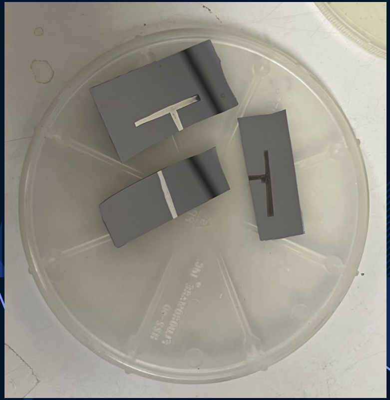
- Circuit model helps identify where issues exist in the cell
- Measures I_{SC} & V_{OC}
- Identifies issues
  - Shunt resistance
  - Series resistance

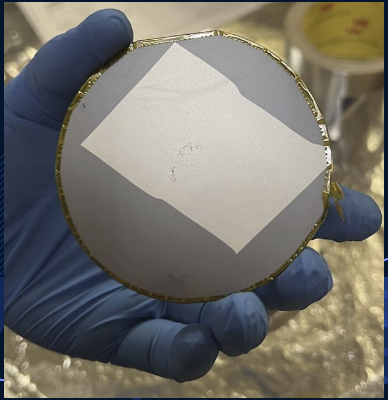


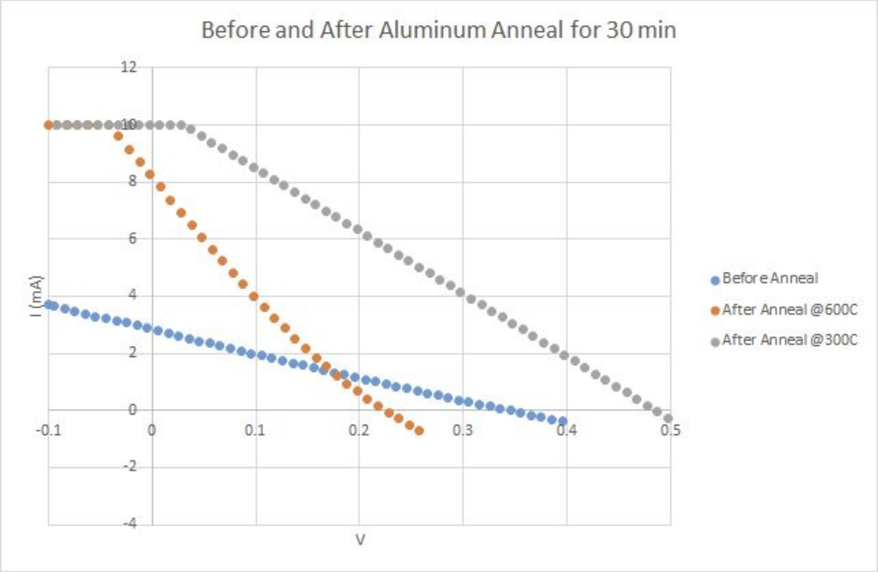


Testing Solar Cell Performance - Silicon

- One of the first experiments was with aluminum annealing temperature
  - Before anneal - V_{OC} = .34V
  - After 600℃ - V_{OC} = .22V
  - After 300℃ - V_{OC} = .48V

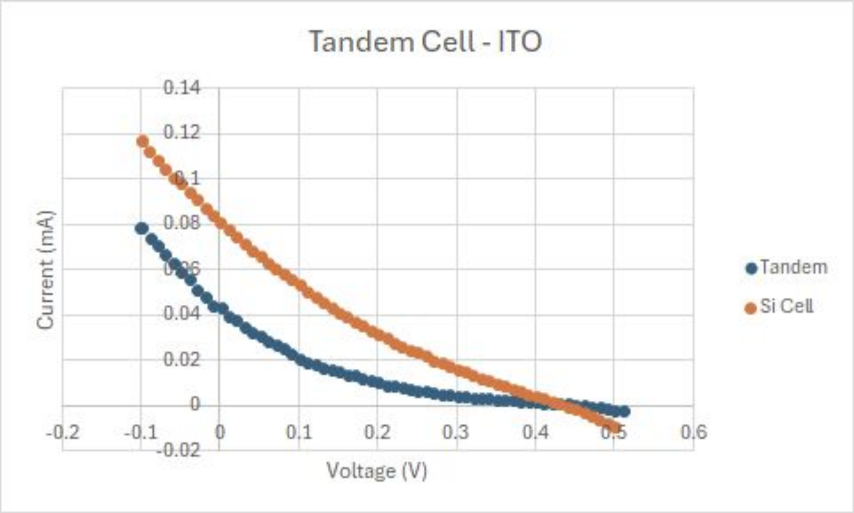


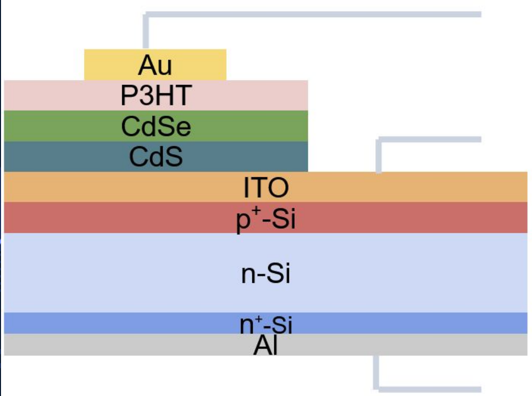




Testing Solar Cell Performance - Tandem

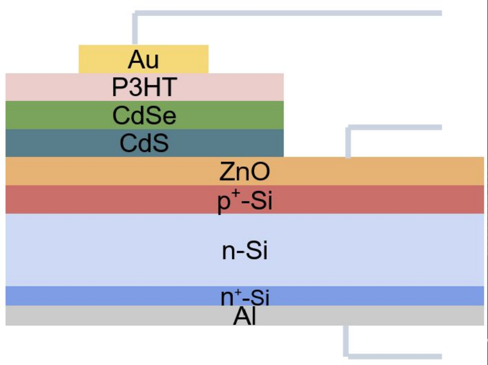
- The tandem cell with ITO interlayer resulted in a highly shunted CdSe cell
  - V_{CdSe}=0V
- After CdSe is deposited, it is annealed at 400°C for 24 hours
  - This annealing is believed to have degraded the ITO layer

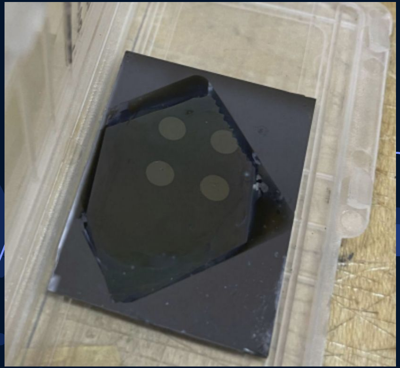


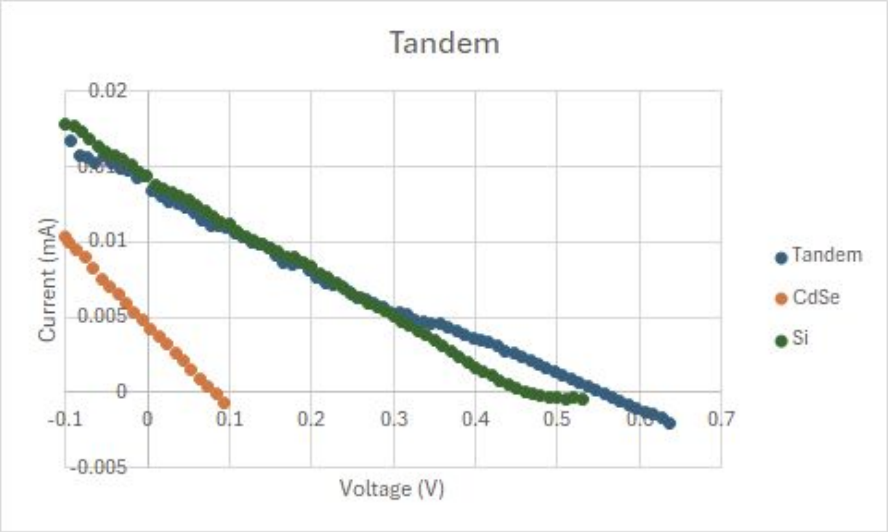


Testing Solar Cell Performance - Tandem

- Tandem cell produced V_{OC} = .56V
- Demonstration of a tandem solar cell with $V_{Si}+V_{CdSe}=V_{Tandem}$
- Largest loss of voltage due to low voltage of CdSe cell







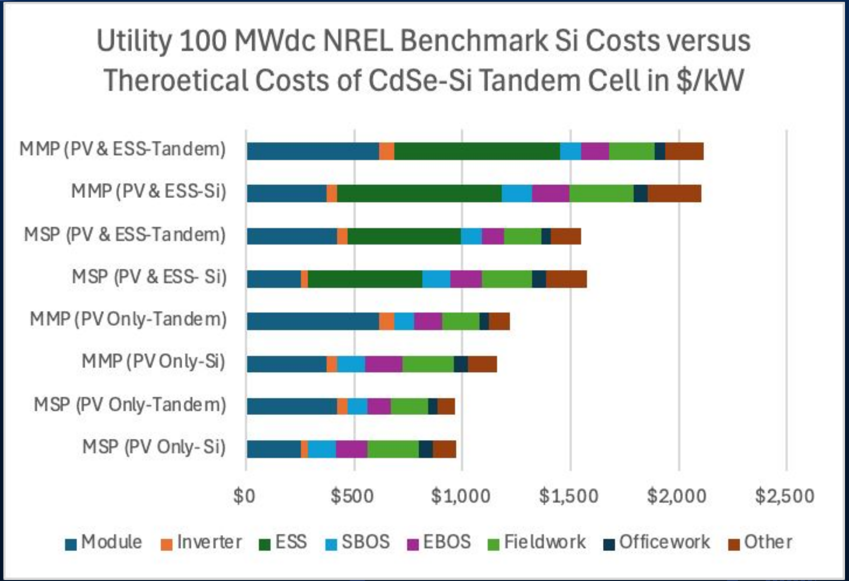
$$Cost\ Per\ Watt\ of\ CdSe\ Cell\ =\ \$0.28/W \frac{32\%}{28\%} = \$0.32/W$$

$$Assumed\ efficiency\ (\%)\ =\ Max\ Theoretical\ Efficiency \times 0.63\ =\ 45\% \times 0.63\ =\ 28.35\%$$

$$Increase\ in\ Efficiency\ =\ \frac{28.35\%}{20.5\%} = 1.383$$

$$Cost\ of\ CdSe - Si\ tandem\ cell\ (\$/W) = \frac{\$0.26/W + \$0.32/W}{1.383} = \$0.42/W$$

- Silicon slightly beats modeled market price of theoretical CdSe-Si cells and tandem cell slightly beats Si for minimum sustainable price.
- Overall, despite similar $/W, tandem cells will still deliver more energy than Si.
- The NREL analysis didn't consider land cost, which would benefit tandem cell $/W costs.



Summary & Future Works

- Demonstrated a Si-CdSe tandem solar cell with two cells contributing to the overall V_{OC}
- Conducted a sustainability and economic analysis of CdSe as a tandem solar cell to Si
- The goal V_{OC} of 1.2V was not achieved, but points for improvement are:
    - Fixing shunt resistance issue of Si and CdSe
    - Optimizing ZnO interlayer thickness
    - Study a-Si as the p-type heterojunction