Studying the relationship between flexibility and efficiency of thin film CdTe photovoltaic devices and a CdTe thin film solar cell design using multi-objective genetic algorithm

Nam Phong Nguyen, Mechanical Engineering Program
Mentors: Johnathan Cappola, PhD student and Lin Li, Associate Professor
School for Engineering of Matter, Transport & Energy (SEMTE)

Abstract:

This research primarily aims to study the efficiency and flexibility of thin film photovoltaic devices. By varying the thickness of each layer in the device, the electrical performance of the device is expected to change. Plastic deformation in these materials, introducing defects to the material, will likely decrease the efficiency of the device. This makes yielding a failure criteria for the simulation purposes. Varying in thickness will change how the stress is distributed when the device undergoes a bending load and will likely change which material yields first and where in the cross-section this happens. ANSYS is used to study this aspect of interest, while SCAPS 1D is used to estimate the electrical efficiency of the device. Studying and optimizing both flexibility and electrical efficiency, this paper intends to better understand their relationship and attempt to design a solar cell that is flexible and efficient.

Motivation

- Thin film flexible solar cells are advantageous over traditional silicon cells in deployment and versatility.
- CdTe specifically has a relatively small band gap while absorbing lower wavelengths, giving it a high potential to convert sunlight into electricity.
- Developments like the introduction of BSF (back surface field layer) and manufacturing processes like CdCl treatment have improved CdTe photovoltaic cells efficiency over the years.
- Over the past year, First Solar has been making consecutive advancements in producing CdTe cells with record efficiency, the most recent being 23.1%.
- CdTe has been known for its cheap manufacturing cost because of the abundance of Cadmium, while Telluride is rare but often obtained as a by-product.

CdTe has certain drawbacks, such as Cadmium toxicity and Telluride's rareness. Still, they have maintained a solid position as a widely used semiconductor material in photovoltaic devices.

However, the mechanical aspects of the thin film materials used in CdTe solar cells have not been commonly studied. Industry and researchers' focus has primarily been placed on the electrical performance of the device. This paper seeks to explore the mechanical side of these devices and optimize it along with solar efficiency.

Methodology

Simulation set up:

Superstate structure CdTe cell:

Au:	0.1 [um]
ITO:	0.1 [um]
glass substrate:	0.1 [um]
ZnTe:	0.01 – 1 [um]
CdS:	0.01 – 1 [um]
CdTe:	0.5 – 10 [um]

The electrical properties of all the layers were found in literatures for SCAPS 1D

* Thin film materials, CdS, CdTe, and ZnTe, do not readily have mechanical properties from literature, so yield strength was estimated as 0.3 of Peierls' stress

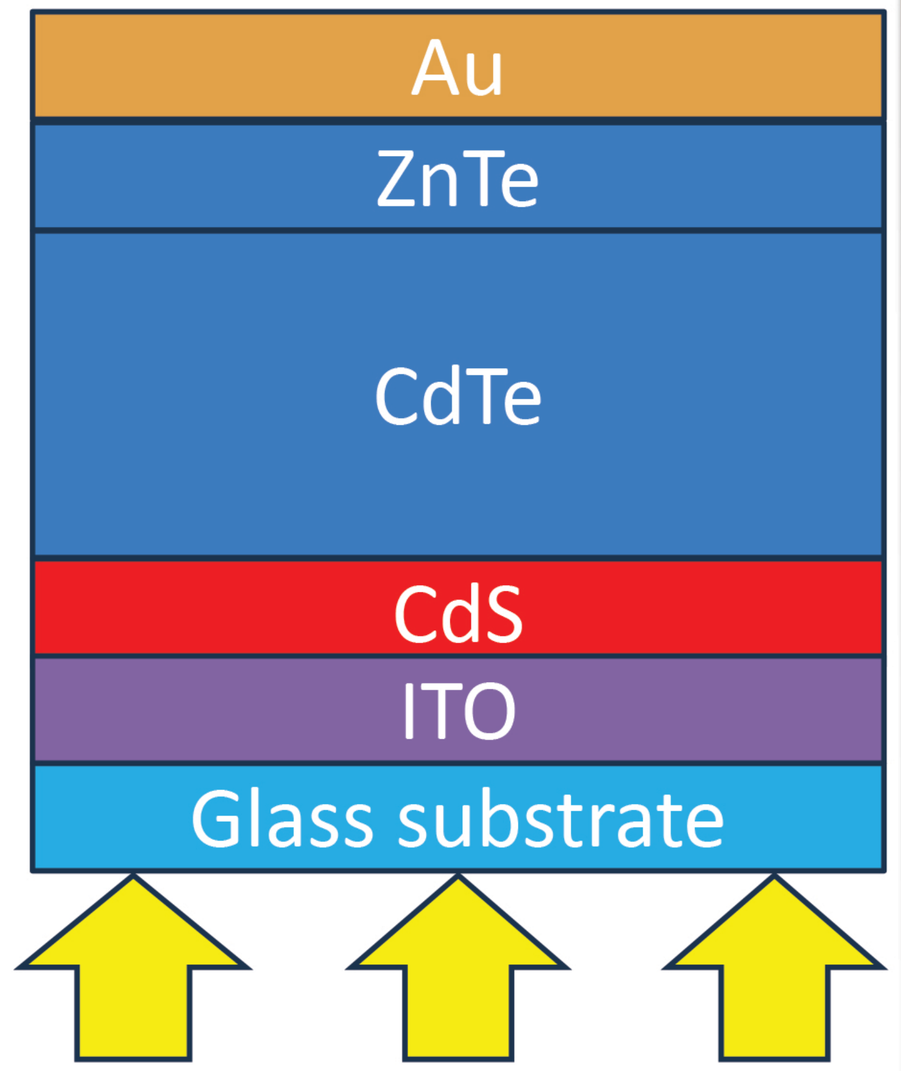


Figure 1: photovoltaic cell structure

Model Framework

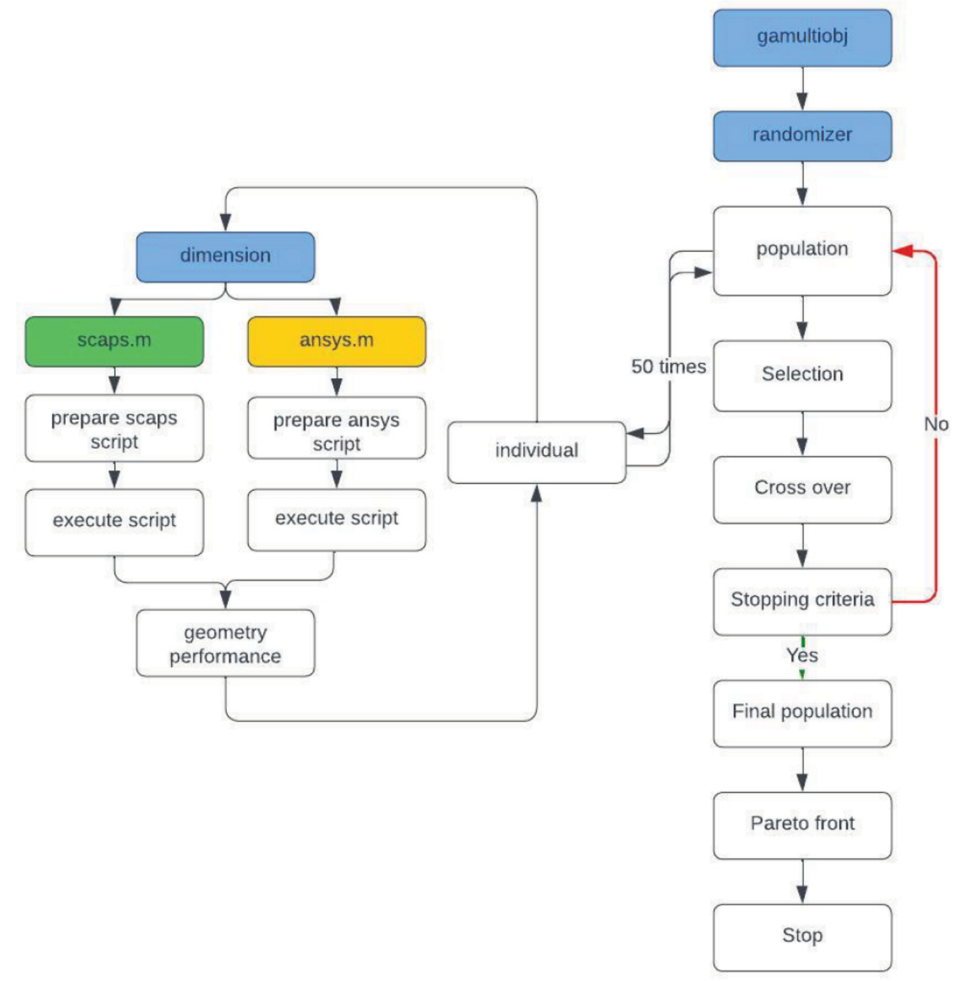


Figure 2: MATLAB flow chart (NSGA II)

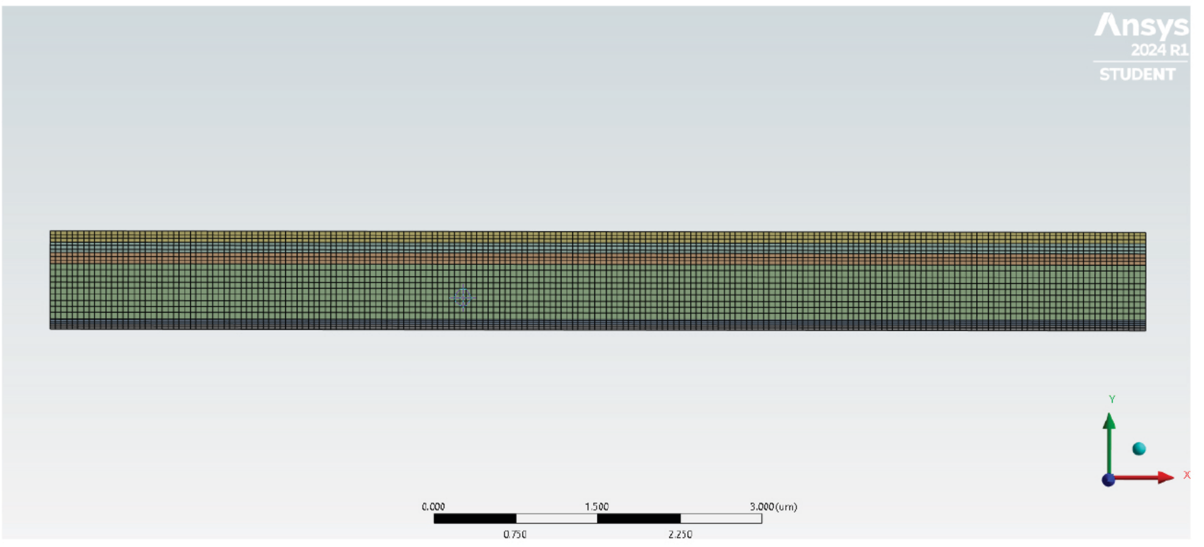


Figure 3: 10 um beam template

2 different functions were created in MATLAB, taking the input of thickness of the three layers (CdS, CdTe, and ZnTe). One of these functions will take that input, generate a script file for ANSYS, and execute this script to obtain the yield bending angle of the geometry. The other function will create a script file for SCAPS 1D and execute it to achieve the same geometry efficiency. The gamultiobj (NSGA II) function in MATLAB will then take in these functions to generate a Pareto front, with which the engineer or the designer will have the option to decide which of the points on that Pareto front best suits the design's application purposes.

Results and Discussion

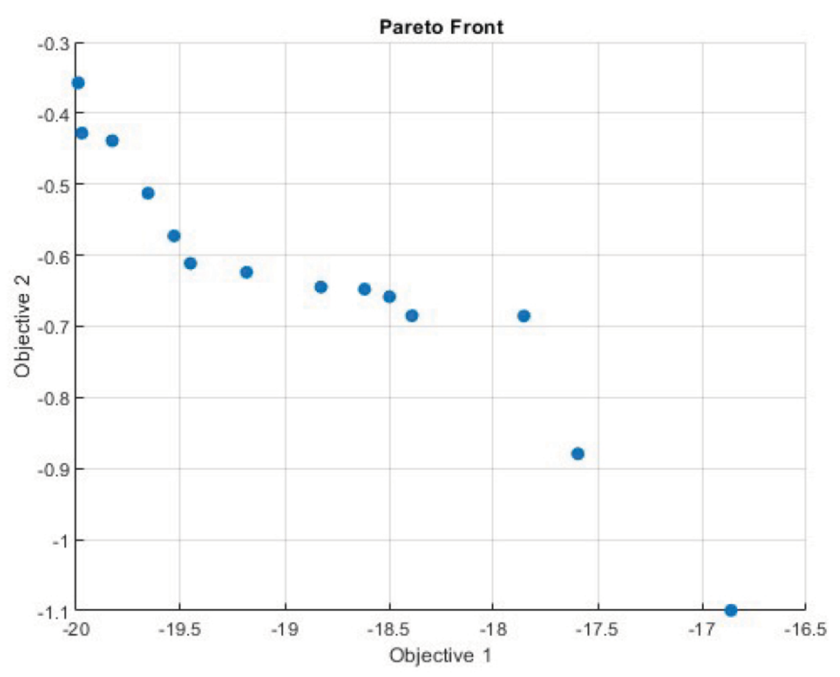
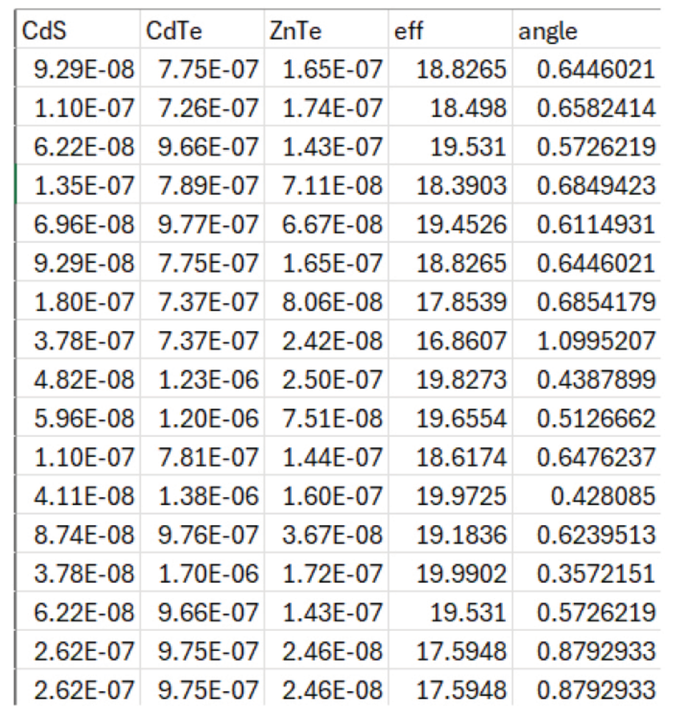


Figure 4: Pareto front



CdS	CdTe	ZnTe	eff	angle
9.29E-08	7.75E-07	1.65E-07	18.8265	0.6446021
1.10E-07	7.26E-07	1.74E-07	18.498	0.6582414
6.22E-08	9.66E-07	1.43E-07	19.531	0.5726219
1.35E-07	7.89E-07	7.11E-08	18.3903	0.6849423
6.96E-08	9.77E-07	6.67E-08	19.4526	0.6114931
9.29E-08	7.75E-07	1.65E-07	18.8265	0.6446021
1.80E-07	7.37E-07	8.06E-08	17.8539	0.6854179
3.78E-07	7.37E-07	2.42E-08	16.8607	1.0995207
4.82E-08	1.23E-06	2.50E-07	19.8273	0.4387899
5.96E-08	1.20E-06	7.51E-08	19.6554	0.5126662
1.10E-07	7.81E-07	1.44E-07	18.6174	0.6476237
4.11E-08	1.38E-06	1.60E-07	19.9725	0.428085
8.74E-08	9.76E-07	3.67E-08	19.1836	0.6239513
3.78E-08	1.70E-06	1.72E-07	19.9902	0.3572151
6.22E-08	9.66E-07	1.43E-07	19.531	0.5726219
2.62E-07	9.75E-07	2.46E-08	17.5948	0.8792933
2.62E-07	9.75E-07	2.46E-08	17.5948	0.8792933

Table 1: Pareto points

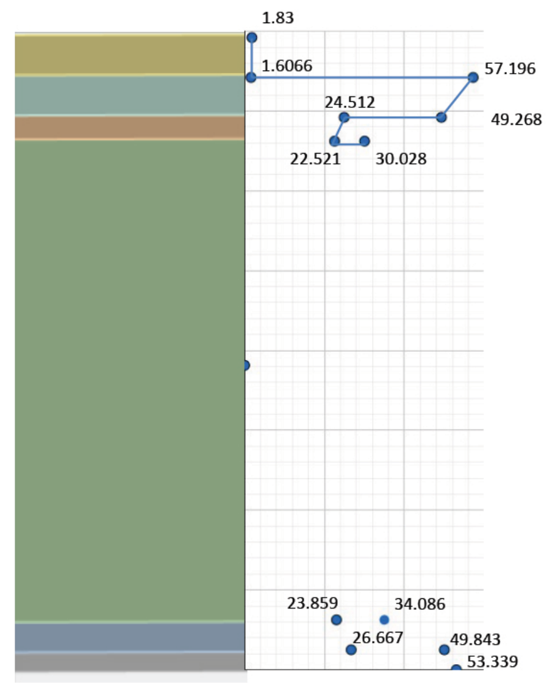
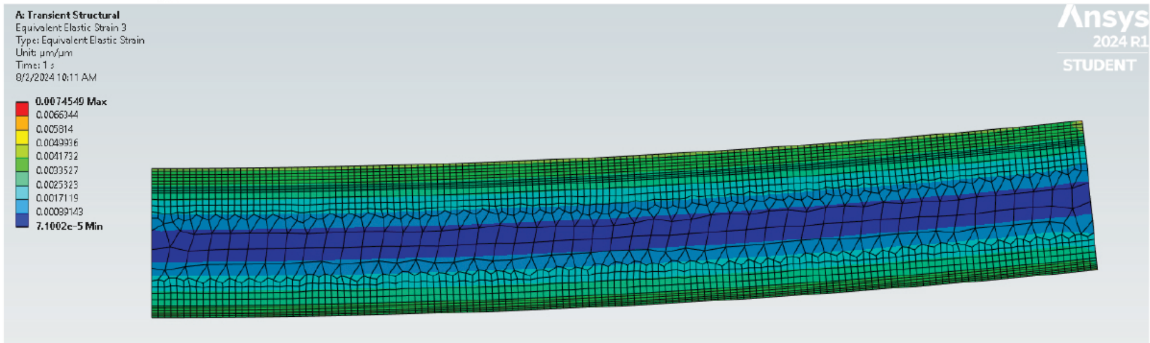


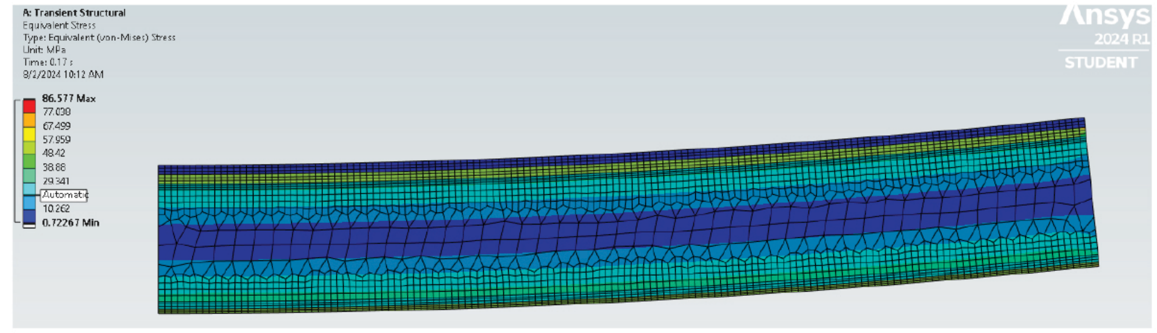
Figure 5: stress distribution

Results and Discussion

One geometry, highlighted above, was chosen to display below that has an efficiency of about 19.66% and yield when bent at a 0.5-degree angle, meaning it can have a radius of curvature of 1.226 mm and a maximum strain on the outer layer of 0.07%.



Figures 6a: ANSYS Transient (Strain)



Figures 6b: ANSYS Transient (Stress)

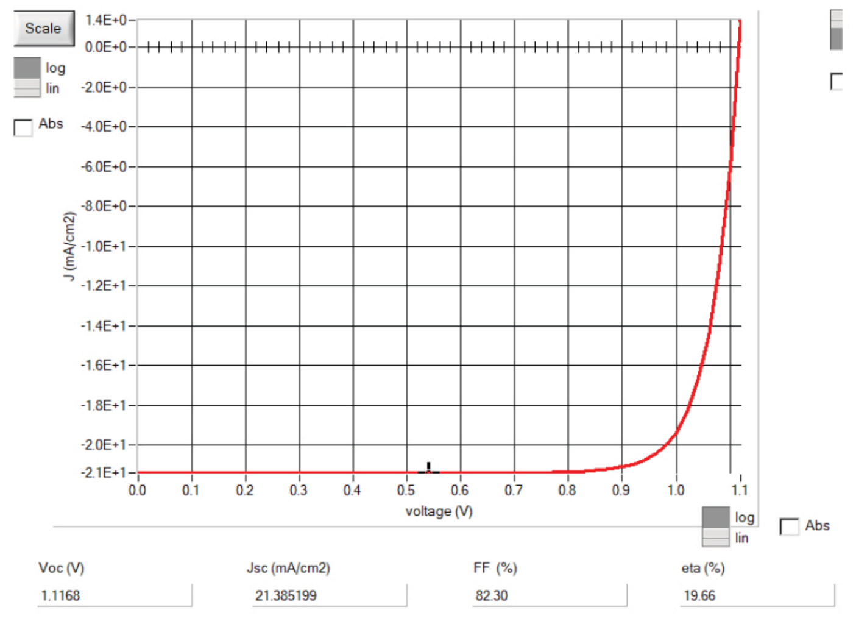
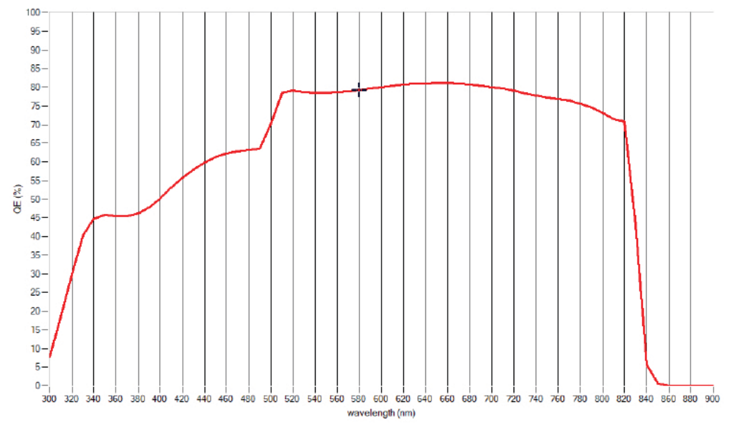


Figure 7: SCAPS-1D JV curve



Figures 8: ANSYS Transient

Due to lack of simulation running time, the Pareto front might not be optimal. Various assumptions were made in this research, such as characterizing material failure at the yielding point; different layers play different roles in these complex designs. Yielding and introducing defects might significantly affect electrical efficiency if the layers were CdTe or CdS. Still, it might be flawed if the layer's defect has little impact on the cell's performance.

- Better characterizing failure points depending on the layer's materials and purposes can be a place to improve.
- Further experimental research to acquire the mechanical properties of thin film material could also be a future project.

Acknowledging certain deficits, this research attempted to create a framework that helps design thin film photovoltaic devices considering solar efficiency and mechanical characteristics.

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