Master's Thesis Engineering Technology

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Optimization of thin film chalcogenide solar cell baseline proces

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Master of Energy Engineering Technology

Context

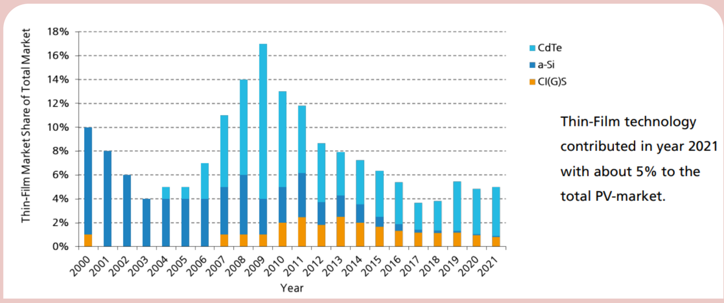


Figure 1: Thin-film market share of total PV-market [1]

In a world where it is necessary to phase out fossil energy due to its effect on global warming, solar energy is a good alternative to fossil energy. The most well-known way of harvesting solar energy is with silicon-based solar cells, but silicon-based solar cells have some physical limits and are therefore not applicable everywhere, **thin-film solar cells** are able to fill that gap. They can be used in **different applications that require them to be lightweight or flexible**. There are different types of thin film solar cells such as cadmium telluride (CdTe), amorphous thin-film silicon (a-Si, TF-Si), but this master's thesis focuses on **Copper indium gallium disulfide diselenide (CIGS)**. These CIGS solar cells have following structure:

1. Substrate: soda lime-glass is insulating and stable to process the depositions of the other layers;
2. Molybdenum (Mo) back electrode to collect all the holes;
3. The **absorber layer** is a **positively doped semiconductor** (P-type) that consists out of $Cu(InGa)Se_2$;
4. Buffer layer is a negatively doped (N-type) semiconductor that consists of cadmium sulphide (CdS) and in combination with the absorber layer is the PN-junction;
5. Zinc Oxide layer (ZnO) and an Indium-doped Tin Oxide (ITO) window layer form the upper electrode that collects all electrons [2].

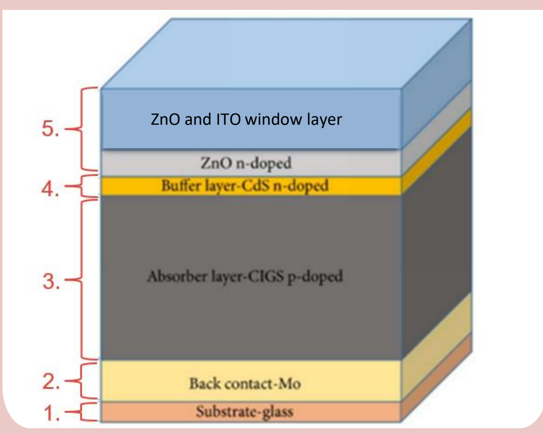


Figure 2: Representation of the standard stack of a CIGS based solar cell [2]

Objective

For the fabrication of the absorber layer, the **two-step process** is used. First copper and gallium are sputtered together at a temperature of 30°C, then the indium layer is sputtered at 150°C, This procedure is repeated 10 times to achieve a stack of 10 layers as shown in Figure 3. On top of this stack a 2-3µm layer of Selenium is capped.

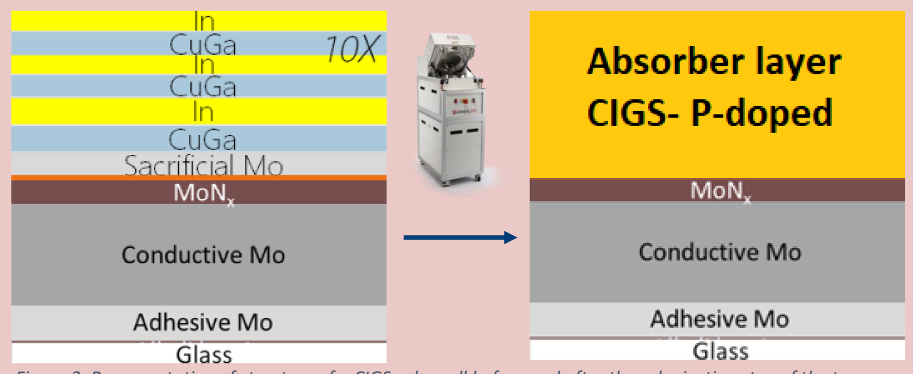
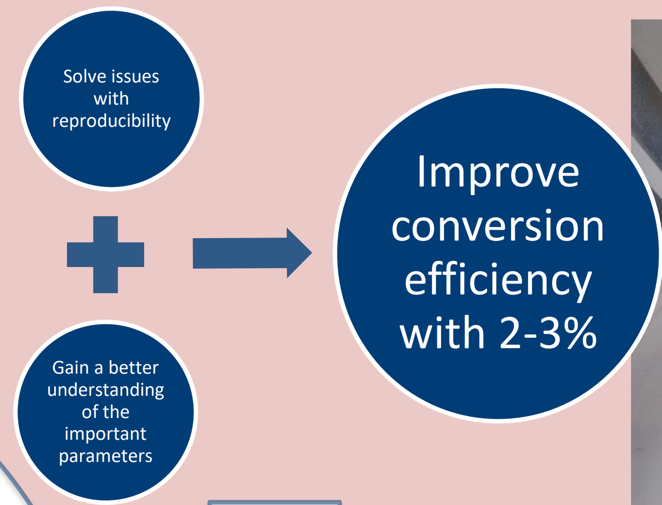


Figure 3: Representation of structure of a CIGS solar cell before and after the selenization step of the two-step process

For the second step this metallic precursor is put in a graphite box and placed in the **Annealsys-AS one furnace** (see Figure 4) for selenization to form the absorber layer. The objective of this master's thesis is to **improve the selenization process** of the imo-imomec group. To achieve this, it is necessary to better understand the parameters during selenization and to solve the efficiency reproducibility problem.



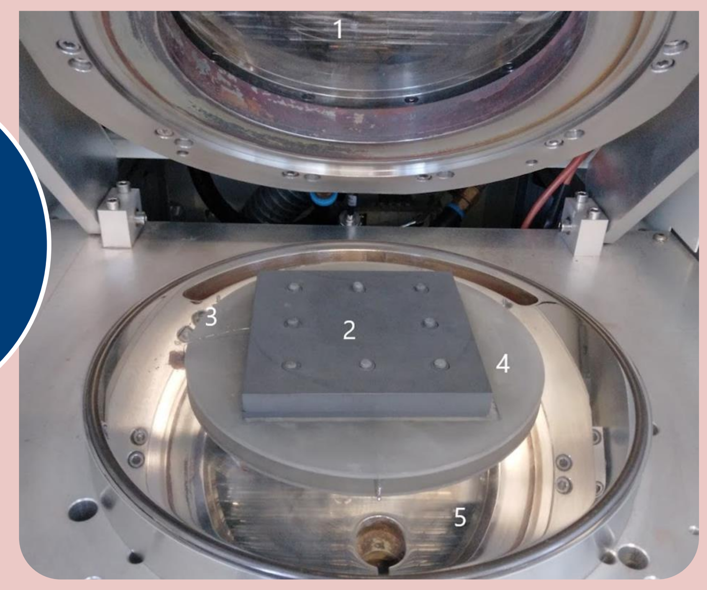


Figure 4: Chamber view of an annealsys AS-one with 1) lamp furnace, 2) graphite box, 3) thermocouple, 4) quartz plate, 5) bed plate

Results

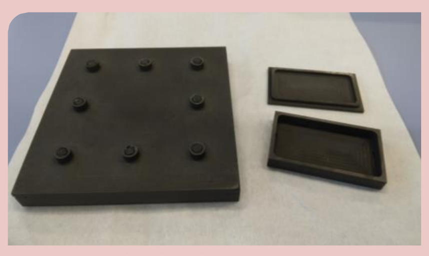


Figure 7: graphite box designs

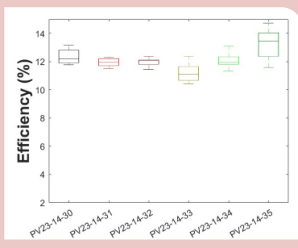


Figure 8: efficiency runs of new box

- ✓ **Baseline stability experiment** showed that the old graphite box was not saturated and consumed to much gasses during the selenization process. It therefore consumed and released different amounts of gasses each run. Therefore, a new smaller graphite box was designed and ordered. This solved the efficiency reproducibility problem (see Figure 8);
- ✓ The **OFAT experiment** shows that the ramping speed (X3), anneal temperature (X4), total time of the anneal (X6+X8) and the pump out temperature (X9) are the most important parameters. All the other parameters seem to be less influential;

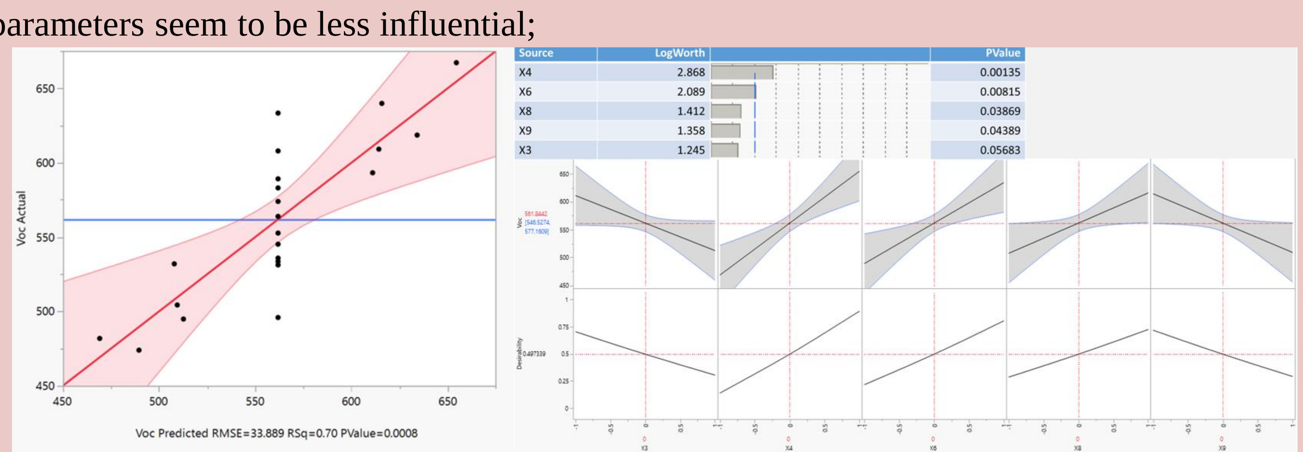


Figure 10: Influence of Ramping speed (X3), anneal temperature (X4), anneal time (X6), post-anneal time (X8) and pump out temperature (X9) on the V_{oc}

- ✓ After implementing the results of the OFAT experiment while using the new designed smaller graphite box several adjustments to the baseline recipe (see Table 2) were made. These adjustments result in a **new baseline recipe** with an increased average efficiency from 13,3% to 15,9% showed in Figure 11 and after ARC a champion cell of 16,7% .

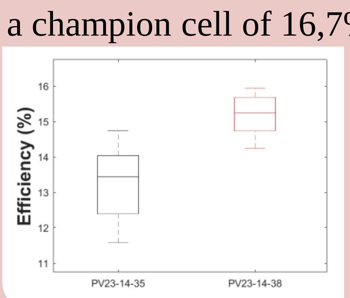


Figure 11: efficiency old versus new recipe before ARC

Table 2: comparison of parameters between the old and new baseline

Parameter number	Parameters	Unit	Old baseline	New Baseline
X1	H_2S pressure T_0	mbar	30	30
X2	N_2 pressure T_0	mbar	670	670
X3	Ramping speed	C/s	10	2
X4	Anneal temperature	C	570	550
X5	H_2S flow during T_1	sccm	20	20
X6	Anneal time $T_1 + T_2$	min	5+5	5+5
X7	H_2S pressure post-anneal	mbar	20	20
X8	Post-anneal yime T_3	min	1	3
X9	Pump out temperature	C	400	100

Material & methods

During this master's thesis following tools were used:

- ✓ **Annealsys AS-one furnace** for the fabrication of the absorber layer;
- ✓ **PL microscope** (Figure 5A) that measures the lifetime and the peak of the bandgap;
- ✓ **SEM** (Figure 5B) to assess the structure of the absorber layer;
- ✓ **Oriel IV-setup** (Figure 5C) to do the solar cell characterization with current-voltage measurements.

Figure 5: Characterization devices with A) photo-luminescence microscope (PL), B) Scanning electron microscope (SEM), C) oriel IV-setup

The used methods in this master's thesis are:

- ✓ **Baseline stability experiment** where different chamber setups of the Anealsys-AS One are tested with the same baseline (see Figure 6) to solve the reproducibility problem;
- ✓ To get a better understanding of the baseline parameters a **One Factor A Time (OFAT) experiment** is carried out where only 1 parameter from the baseline recipe is changed each run;
- ✓ The knowledge of the OFAT experiment and the baseline stability experiment is implemented to **find a new baseline**.

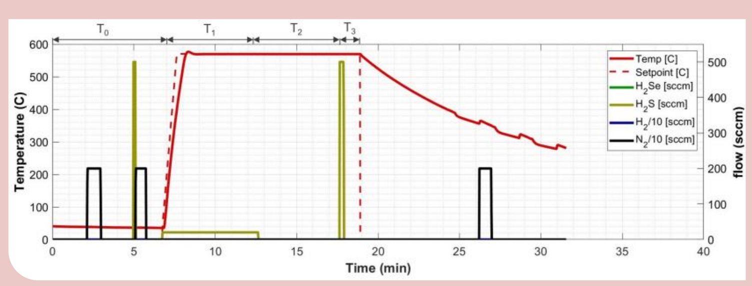


Figure 6: Baseline temperature-SCCM-time graphic of the selenization process

Table 1: Parameters of the OFAT experiment

Parameter number	Parameters	Unit	-	Baseline	+
X1	H_2S pressure T_0	mbar	0	30	150
X2	N_2 pressure T_0	mbar	0	670	300
X3	Ramping speed	C/s	2	10	15
X4	Anneal temperature	C	550	570	590
X5	H_2S flow during T_1	sccm	0	20	40
X6	Anneal time $T_1 + T_2$	min	2+2	5+5	10+10
X7	H_2S pressure post-anneal	mbar	0	20	100
X8	Post-anneal time T_3	min	0	1	3
X9	Pump out temperature	C	100	400	550

Supervisors / Co-supervisors / Advisors: Prof. dr. Guy Brammertz
Prof. dr. Bart Vermang

[1] Fraunhofer Institute for Solar Energy Systems, ISE with support of PSE Projects GmbH. *Photovoltaics report* [Online]. url: https://www.ise.fraunhofer.de/content/dam/ise/de/documents/publications/studies/Photovoltaics-Report.pdf.

[2] Billel Salhi. "*The Photovoltaic Cell Based on CIGS: Principles and Technologies*". In: Materials 15.5 (Mar. 2022), pp. 1–27. issn: 19961944. doi: 10.3390/ma15051908.

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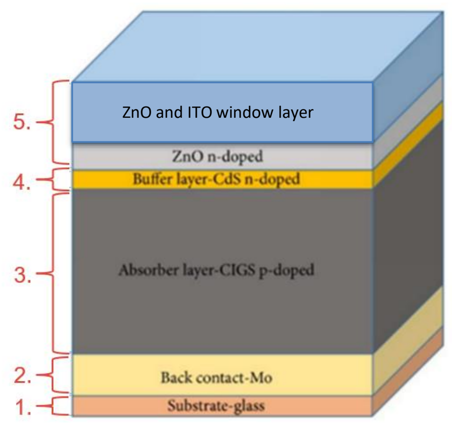

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