

Tuesday, 1/27/26

## Other Types of Semiconductor PV Devices

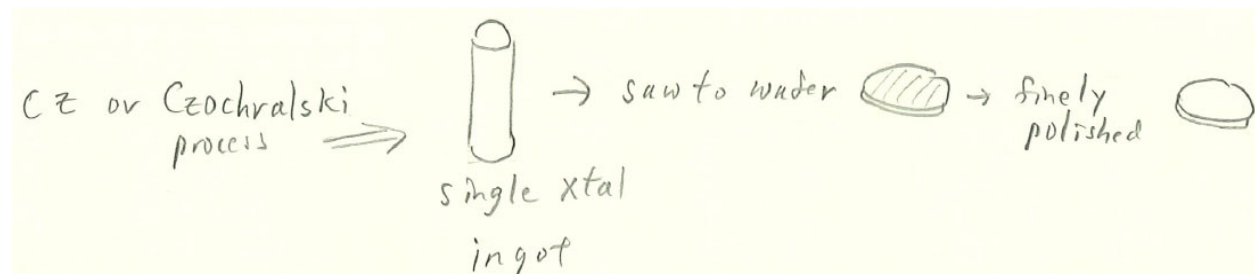
So far, we have primarily looked at monocrystalline (or single-crystal) Si PV cells. But there are other types of semiconductor PV technologies.

### 1. Polycrystalline Si PV

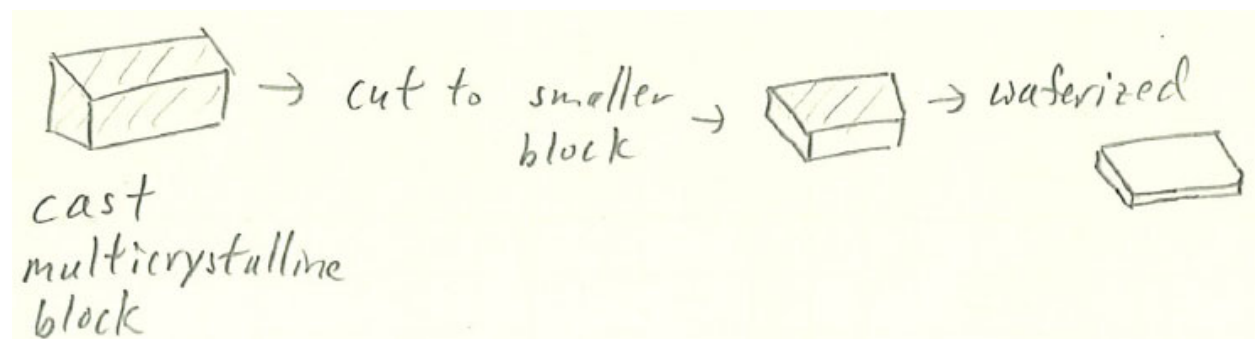
Also called multicrystalline Si PV (MCSi PV).

Its performance is similar to that of single crystal Si PV (SCSi PV: “SC” – “single crystal”), but it has slightly lower efficiency (about 1% less). However, the manufacturing process is very different:

Monocrystalline Si PV manufacturing process (similar to microelectronics fabrication)



Multicrystalline Si PV manufacturing process



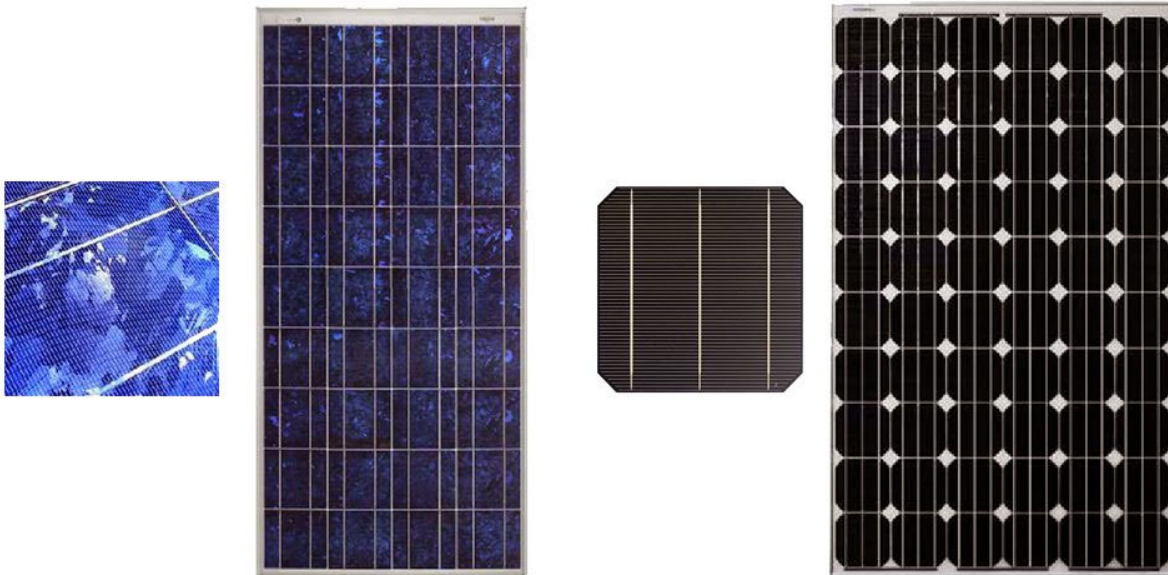
Although MCSi PV is about 1% less efficient than SCSi PV), it has 2 advantages:

- (1) MCSi PV costs less (lower cost manufacturing process),
- (2) MCSi PV cells are made rectangular: they can be packed more densely than rounded SCSi PV cells: better usage of the area exposed to the sun.

MCSi PV cells are manufactured as rectangular. SCSi PV are manufactured as (mostly) round, but they are “squared” by cutting a rounded-corners square out of the center, which wastes a portion of each Si wafer.

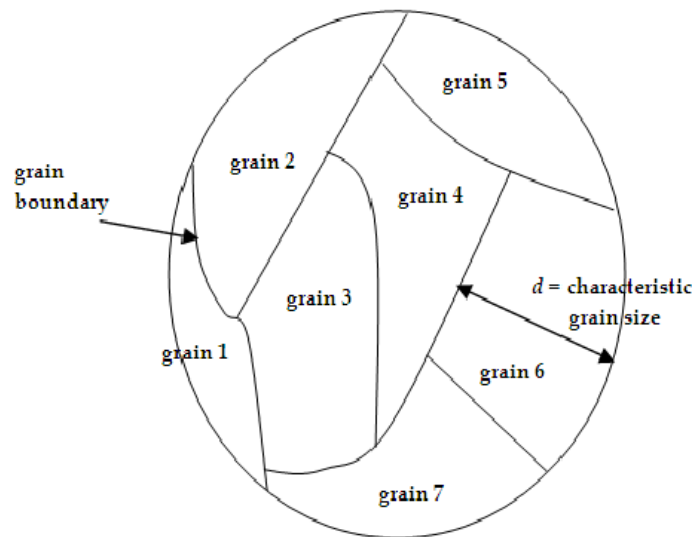
MCSi PV cells have a scaly, shimmering blue distinctive appearance (the “blue” is the antireflective coating).

Multicrystalline PV on left, Monocrystalline PV on right:



Courtesy: [Monocrystalline-vs.-Polycrystalline-e1514089013744.jpg \(1000×666\) \(wp.com\)](#)

Polysilicon has grain boundaries between individual crystal grains of different crystal orientations:



Courtesy: [Grain-boundaries-of-polysilicon.png \(510×376\) \(researchgate.net\)](#)

These grain boundaries present unwelcome sites for electron-hole recombination, hence MCSi PV have lower efficiencies than SCSi PV.

## 2. Amorphous Si (a-Si) PV

This was the first “thin-film” PV technology.

It is easy to manufacture and low-cost.

It has lower efficiency than SCSi PV and MCSi PV, about 6-8%, which is about half the efficiency of SCSi PV.

But, a-Si is better than SCSi PV in weak or diffuse light (including indoor applications like powering a calculator).

Also, a-Si PV is less adversely affected by temperature than SCSi PV.

### a. a-Si composition

Amorphous Si is better at absorbing photons than SC Si: very thin films can be used → ~ 1  $\mu\text{m}$ .

It has no regular crystal lattice structure: it has a random structure.

This results in many incomplete bonds and therefore many defects, which result in energy stepping stones between valence and conduction bands → promotes recombination.

The non-crystalline structure results in low charge carrier mobility.

However, various techniques have been developed to overcome these issues.

#### b. Minimizing recombination in a-Si PV

Since a-Si has a randomly ordered structure with dangling bonds, this structure provides sites that promote recombination.

One technique to improve this is to add hydrogen (H), resulting in a-Si(H).

Hydrogen atoms bond to the dangling Si bonds and passivate them.

Another useful characteristic of a-Si(H) is that it can be doped n-type and p-type.

The  $E_G$  of a-Si(H) is 1.75 eV, compared to  $E_G = 1.12$  eV for SCSi.

1.12 eV : 1.107  $\mu\text{m}$  – IR band

1.75 eV : 0.708  $\mu\text{m}$  – visible light (red) band

Also, a-Si(H) is a direct bandgap semiconductor, unlike SCSi.

#### c. Improving low charge-carrier mobility

Also known as “poor carrier transport.”

This can be improved by realizing a p-i-n structure:

p → p-type a-Si(H)

n → n-type a-Si(H)

i → intrinsic a-Si(H): actually lightly doped, slightly n-type.

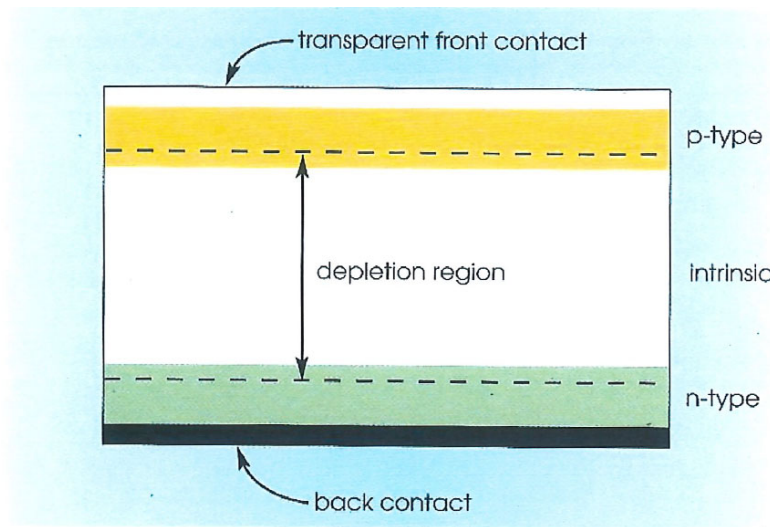
The i-layer greatly increases the width of the depletion region.

If the i-layer is slightly n-doped, then the greatest electric field occurs at the p-i interface.

Therefore, orient the structure so that light enters the very thin heavily doped p-type layer.

Then most of the charge carriers are created near the top of the cell and are successfully collected.

Consider the cell's structure below:



**Figure 2.25** The basic structure of a single-junction a-Si(H) solar cell.

### (1) i-layer drawbacks

The i-layer results in an aging effect, where efficiency decreases over the first few months of use in bright sunlight:

Dependent on the total number of photons,

Typically, a 10% to 30% reduction in the 1<sup>st</sup> 6 months.

This effect is called the “Staebler-Wronski Effect”: it is named after the two people who discovered it in 1977. Its exact cause is still not fully understood.

It is caused by the i-layer creating additional defects that aid in recombination.

The cell somewhat recovers if heated, which could occur during summer use.

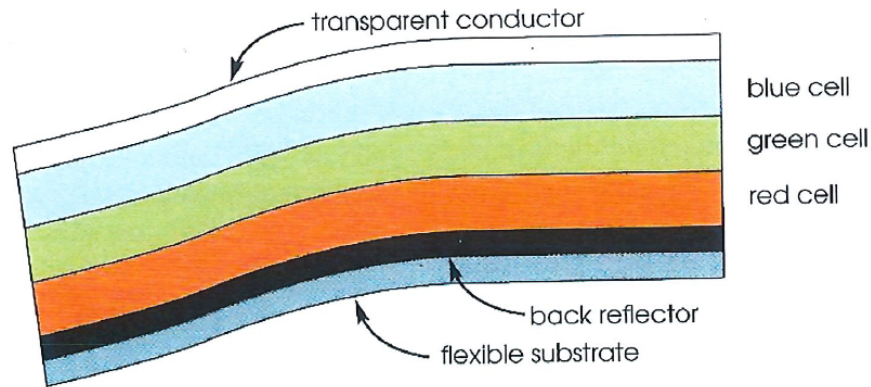
## (2) Overcoming the Staebler-Wronski effect

A “multi-junction” or “stacked cell” structure can be used, with two or more thinner i-layers.

In this case, stack cells with different bandgaps.

This enables the capture of a larger percentage of solar photons, with good stability and efficiency.

Consider the triple-junction cell structure below:



**Figure 2.26** A triple-junction amorphous silicon solar cell.

The top cell is the “blue cell” → a-Si:  $E_G \approx 1.75$  eV → high energy photons captured.

The mid cell is the “green cell” → a-Si-Ge(15%):  $E_G \approx 1.6$  eV → lower energy photons captured.

The bottom cell is the “red cell” → a-Si-Ge(50%):  $E_G \approx 1.4$  eV → lowest energy red and IR photons captured.

The textured backside reflector reflects unabsorbed photons back up through the cell where they may be captured.

The cell is very thin and can be made flexible (as shown above), such as formed on a roll of plastic film (continuous roll-to-roll manufacturing).

### 3. Microcrystalline Si

This material can be deposited in thin layers  $\sim 1\mu\text{m}$ .

However, like SCSi, it has poor light absorption.

If effective light trapping technologies can be developed, then this thin-film Si PV technology might be able to match the efficiency of SCSi PV.

### 4. Other Thin Film PV Technologies

New types of non-Si semiconductor PV technologies are competing with Si for market share.

Particularly in the U.S. since worldwide Si PV production has largely moved to China.

Many of these new types of PV technologies are heterojunction devices.

A homojunction device uses the same base material for both n-type and p-type material. Both the n-type and the p-type layers have the same  $E_G$ .

A Si pn junction is a homojunction.

For a heterojunction, one material is the n-type layer and a different material is the p-type layer. The n-type and p-type materials have different  $E_G$ 's.

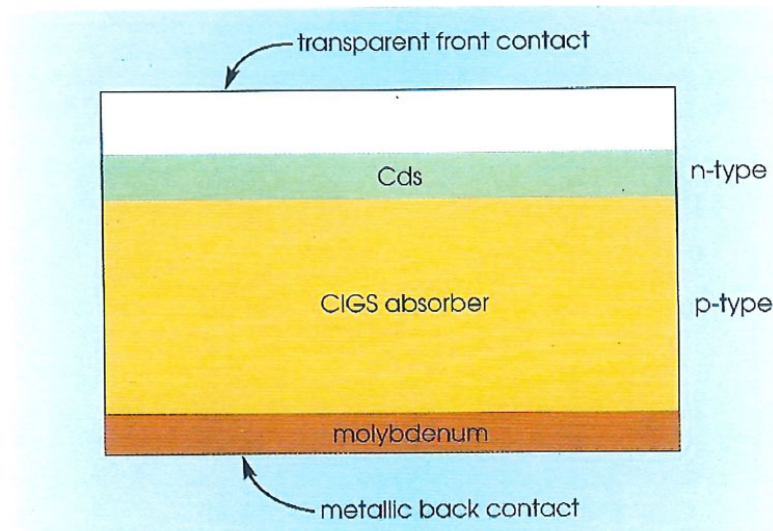
In addition to PV cells, heterojunctions can be used to make lasers, BJTs, and FETs.

An example is the GaN FET, a high electron mobility transistor (HEMT).

### a. Copper Indium Diselenide (CIS) PV

This is a I-III-VI<sub>2</sub> semiconductor material composed of copper, indium, gallium, and selenium. When gallium is added, it is called CIGS.

Consider the drawing below:



**Figure 2.28** The basic scheme of a CIGS solar cell.

CIS or CIGS forms the p-type layer.

The gallium is added to adjust the  $E_G$ .

With no added gallium:  $E_G = 1.1 \text{ eV}$

Gallium can be added to increase  $E_G$  up to 1.7 eV.

CdS (cadmium sulfide) forms the n-type layer.

In 2008, a CIGS based PV cell passed 20% efficiency in the lab, which beat a-Si and approached SCSi PV's efficiency.

Issues:

Indium is a rare earth material with limited quantity.

NOTE: indium has some interesting properties: “screams” when bent, and room temperature cold welding.

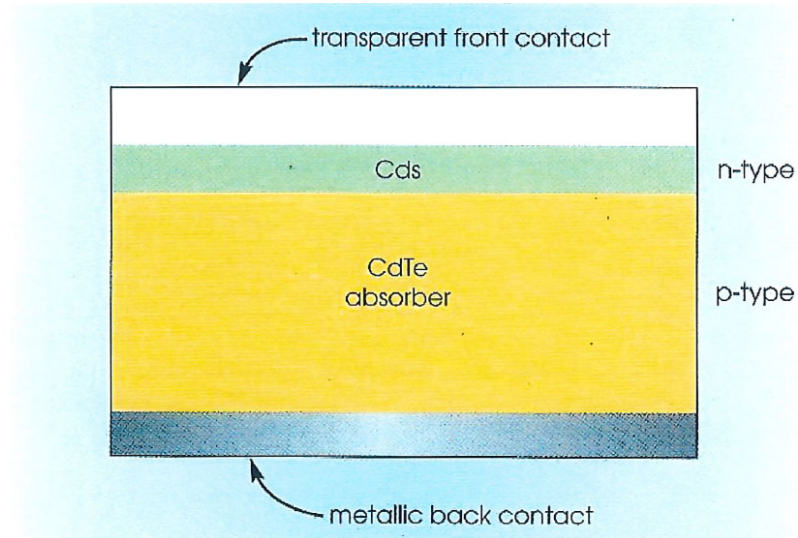
Cadmium is a heavy metal and is highly toxic.



b. Cadmium Telluride (CdTe) PV

CdTe is also a heterojunction semiconductor material.

Consider the drawing below:



**Figure 2.30** A CdTe solar cell.

CdS is the n-type material and CdTe is the p-type material.

The cell has  $E_G = 1.45$  eV, which is close to optimum for the sun's spectrum.

Achieved laboratory efficiency has exceeded 22%.

CdTe PV modules are very inexpensive to manufacture.

However:

Cd and Te are toxic: tellurium can cause really bad breath.

There is some concern about Cd and Te being released into the air if a module catches on fire.

End of life disposal for CdTe and CIS/CIGS PV cells/modules cannot be ignored, since Cd is a highly toxic heavy metal and Te is also toxic.

## 5. Gallium Arsenide (GaAs) PV

This is another rigid cell technology.

GaAs has a  $E_G$  of 1.42 eV, which is better for sunlight than SCSi with an  $E_G$  of 1.1 eV.

GaAs is a direct band gap semiconductor material and is used for high frequency electronics, LEDs, laser diodes, and PV.

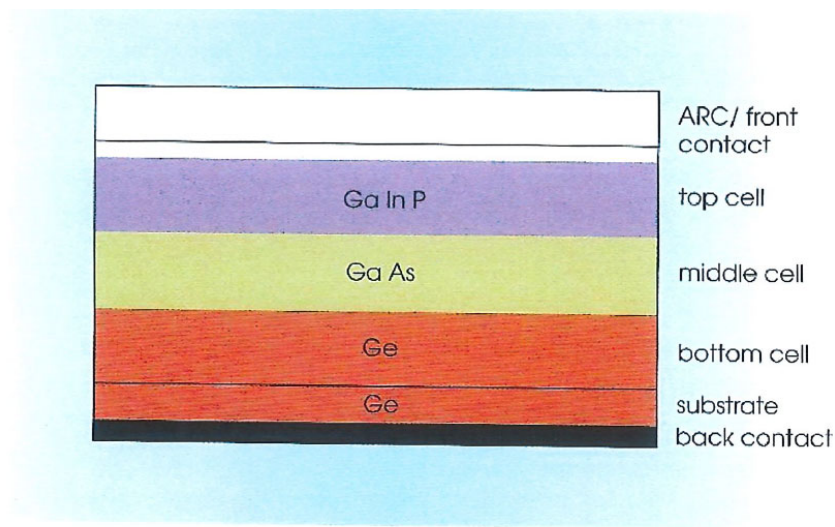
GaAs PV is less susceptible to radiation induced damage than Si PV, and has therefore been used for space PV applications for a long time.

A 15% efficiency was achieved in 1970.

Triple junction GaAs based PV cells have been developed with efficiencies well over 30% (> 40% in the laboratory).

However, GaAs PV is expensive, and is typically used in high-end applications.

Consider the drawing below:



**Figure 2.33** A triple-junction cell.

The top cell is GaInP:  $E_G = 1.9$  eV  $\rightarrow$  captures high energy UV/blue photons.

The mid cell is GaAs:  $E_G = 1.42$  eV.

The bottom cell is Ge:  $E_G = 0.7$  eV  $\rightarrow$  captures low energy IR photons.

GaAs PV is also used on Earth in sunlight concentration systems that use mirrors or lenses to concentrate sunlight onto the GaAs cell/module.