Worksheet 2 Solutions – Materials used in Photovoltaic Modules

1.

Material	Advantages	Disadvantages
Silicon	Second most abundant element on earth surface	almost run out
	Form better semiconductor due to high hole mobility	silicon dioxide can form insulating layer
	cheap to process	
	higher reverse leakage current than germanium	
Germanium	low impurities	lower reverse leakage current
		worse semiconductor property
Gallium Arsenide	has higher saturated electron velocity and higher electron mobility	no insulating layer
	generate less noise than silicon device	
	higher breakdown voltage	
Cadmium Telluride	cheaper than silicon	not used anymore due to toxicity
		not as efficient as others

2. Traditional crystalline silicon is by far the most common solar cell material for commercial applications. It is formed by casting an ingot to produce silicon with crystal structures (either mono or multi). Then these ingots are sawn very thin (typically 300 microns) to produce wafers. Thin film cells can be created by sequentially depositing thin layers of the different materials into a very thin structure directly. The resulting thin-film devices require very little semiconductor material and have the added advantage of being easy to manufacture and cheaper due to low amount of silicon needed. There is no cutting of wafers or casting of ingots.

3. The three principal thin-film technologies are:

- Amorphous silicon (a-si)
- Cadmium Telluride (CdTe)
- Copper Indium Gallium Selenide (CIGS)

In amorphous silicon, the silicon atoms are arranged more randomly than in the strict geometric order found in crystals. The basic structure of CdTe has a glass super substrate and a layer of transparent conducting oxide (TCO) as a front contact, n-type cadmium sulphide and a p-type cadmium telluride, and a metallic rear contact. Copper Indium diSelenide has an extremely high absorption that allows 99 percent of available light to be absorbed in the first micron of the material. CIGS cells have reached efficiencies of more than 19 percent - much higher than other thin-film PV.

4. Amorphous (a-Si):

Advantages:

- a-si has higher absorption coefficient and it absorb more strongly especially for lower wavelength light
- require low film thickness, and hence,
- potential for lower cost
- less subject to output reduction due to heat
- more tolerant of reduced intensity and diffused light.

Disadvantages:

- lower efficiency due to low grade silicon
- long term degradation due to exposure of light
- production has been declining due to the difficulty in increasing its efficiency
- production require hazardous gas

Cadmium Telluride (CdTe):

Advantages:

- high efficiency (over 16%)

Disadvantages:

- High processing temperature, and as a result CdTe can only be manufactured in superstrate
- Perception that CdTe devices will be unstable and degrade in outdoor environment
- Toxicity of cadmium
- Uncapsulated cells are sensitive to moisture

Copper Indium Gallium Selenide (CIGS)

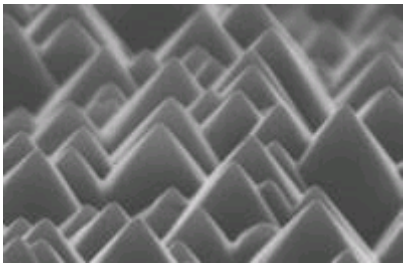
Advantages:

- Higher efficiencies compare to other thin film material
- Economical material and processes
- There is clear pathways to increase performance

Disadvantages:

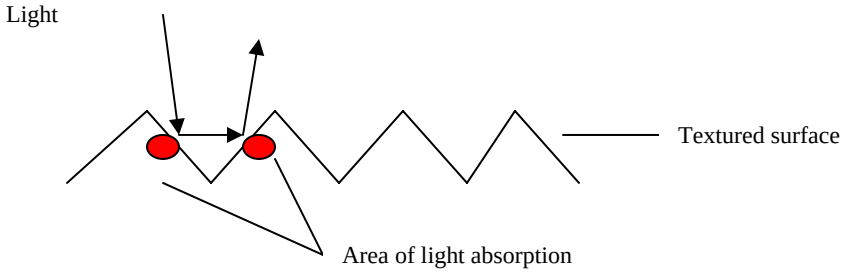
- Not as abundant a base material as silicon

5. Texturing reduces the reflectivity of a mono-crystalline silicon surface by forming pyramids as shown in the diagram below:

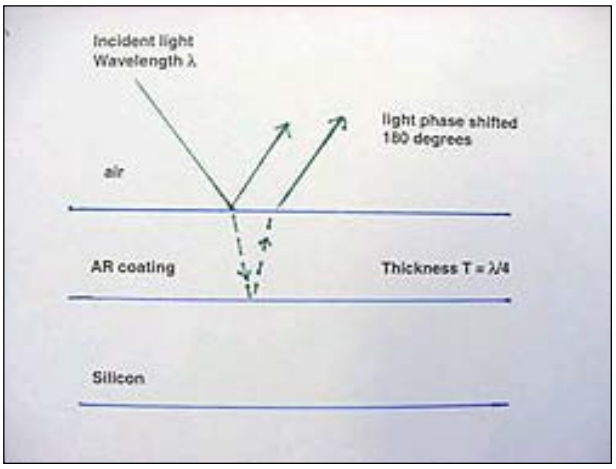


The pyramids are formed by the use of anistrophic etch of sodium hydroxide and isopropanol (etch different plane of silicon at different rate). The pyramids formation depends on several different factors such as: the concentration of NaOH and isopropanol, and the time of etch.

This pyramids help to reduce reflectivity of the surface by reflecting the light to another pyramid and hence there will be more chance for absorption as shown in the diagram below.



The figure below shows a schematic of a silicon surface coated with a dielectric layer of thickness T.



The mechanism by which the Antireflection coating is able to reduce the surface reflection of silicon is by light reflecting from the silicon/dielectric surface being as close as possible to 180 degrees out of phase with the light being reflected from the

air/dielectric interface, with the two reflected components therefore acting to cancel each other out.

The 180 degree phase shift is achieved for a given wavelength λ by making the thickness of the dielectric layer $T = \lambda /4$ (where λ is the wavelength the light has within the dielectric layer). The reflected light will therefore have a phase shift of half a wavelength (2T) and therefore destructively interfere with the light component reflected from the dielectric/air interface to reduce the total reflection.

6. The metal that is usually used for the formation of rear metal contact is Aluminium. The front metal contact is usually silver because it has a higher electrical conductivity and is only needed in small quantities to prevent shading of light reaching the top surface.

7. *Single Crystal silicon (Mono-crystalline)*

Single crystal silicon wafers currently satisfy a significant but declining fraction of the solar cell market.

Advantages:

- They are already produced for other markets
- They allow for higher efficiencies solar cells

Disadvantages:

- Require higher quality feedstock
- More expensive and circular, leading to lower packing densities in module

As shown in the table above, the common growth techniques for monocrystalline wafers are Cz and FZ. Cz wafer are lower in quality due to the presence of grain boundaries. FZ wafers has more pure and lower defect crystals. As a result, monocrystalline wafers produced by FZ technique will be more expensive

Multi-crystalline and Polycrystalline

These two terms have previously been used interchangeably in different texts, however, there are actually significant differences between these two terms, which mainly is their grain size, as shown in the table above. These two crystal silicon have disadvantages in that they have more defect than monocrystalline, and hence lower efficiencies.

Ribbon Silicon

Ribbon silicon is a technique used to grow multicrystalline silicon. This technique involve the use of two carbon (graphite) filaments and molten silicon in which the molten

silicon will be growth horizontally through capillary action. This will produce a ribbon like sheet of silicon. This technique is currently used mostly by Evergreen Solar.

Advantages:

- thickness can be varied
- cheaper since less silicon can be used

Disadvantage:

- Lower efficiencies

8. Silicon ingots – During the purification the silicon is made molten. In this step the silicon is solidified. There are two main processes used in this stage. The first is the Czochralski method where a single crystal is slowly drawn from a molten silicon vat by slowly rotating the crystal and the cylinder that gradually forms. This creates a long cylinder of silicon that is all one crystal and is known as single crystalline silicon. The second method is easier and much cheaper, and involves pouring the molten silicon into a mould and letting it set. This process forms silicon with many crystals oriented in different directions. The silicon produced is then known as multi-crystalline.