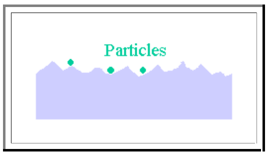
## 8.2.2 Processes and Process Integration

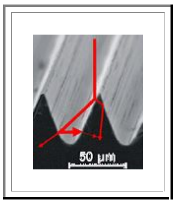
### Overview

- Compared to the complexity of making an integrated circuit, making a solar cell is exceedingly simple. However, to belabor the point once more, making a *very good* and *very cheap* solar cell in a *1 s rhythm* is exceedingly difficult.
  - We will look at the necessary processes an the process integration in a very superficial way. There simply is not enough time to go into details; and the interesting details are kept very confidential at present anyway.
- What are the basic processes we need? Here is a list giving processes and the process integration sequence with short comments

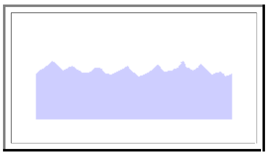
**Surface roughening**




- We must texture the surface in such a way that the reflection of light is reduced. This can be done by "grooving" or by any other way that produces surface textures that direct reflected light back at the **Si**
- The example on the right shows a light path that will still end up in the **Si** even after two reflections took place.
- Regular **Si**, as we know, looks like a metal, i.e. silvery-shiny - in other words it reflects light quite well. Measures for decreasing reflection are absolutely essential - already for low efficiency solar cells. Working on anti-reflection measures might be far more important for high-efficiency solar cells (i.e. $\lambda$ **= 20 %**) than improving junction properties!

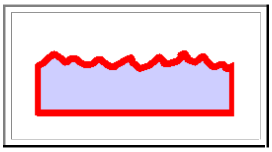



**Surface Cleaning**



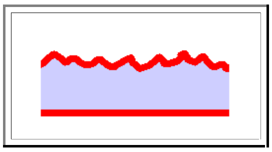
- Your mother is right! Cleanliness is next to Godliness, indeed. At least if you want to make solar cells (or any other semiconductor device).
- We had looked a the particle and contamination problem in the context of integrated circuits before; with solar cell production we have essentially the same problems.
- OK - solar cell structures might not be quite as sensitive to contamination than a **3 nm** gate oxide, but then we also don't want to run our production in an expensive super-cleanroom either. Finding efficient cleaning procedures is a good idea and essential for success.

**Diffusion**



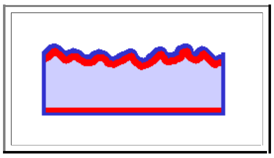
- Now we form the necessary **pn**-junction by diffusion. If our substrate wafer is **p**-type (the standard at present (2008)), we diffuse some phosphorous into the front side to a junction depth of **< 1 µm** (which is far thinner than the red line in the picture!). Note that we do *not* ion-implant the **P** to form the **emitter** of the solar cell (that's what we call this layer) as we would always do in microelectronics - far too expensive!
- We go back to an old-fashioned (and cheap) technique: We "somehow" smear some **P**-containing stuff on the **Si** surface and heat it up. **P** will out-diffuse from the source layer and penetrate into the **Si** if we do it right.
- One version for this is to use the so-called "**POCl**" process - we have encountered that before. But whatever - we will usually end up with a **pn**-junction all around the wafer; front-side, backside and edges, which is, of course, *not good*.

**Edge Isolation**



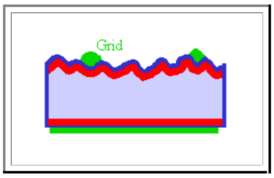
- We now remove the **pn**-junction around the edges, which otherwise would provide an electrical short-cut between front and back!
- Quite easy to draw. How about doing it? Can you come up with a viable process for this (good, quick, cheap, ...)? No! Well - it's not that easy. Obviously we have another quite solar-cell specific process here.
- One way to do is to stack a lot of wafers until you have a block. Then just etch off a few **µm** of the surface by plasma etching.
- One way for achieving edge isolation. There are other ways - and they are more or less confidential, once more

**Passivation**



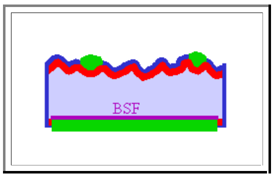
- We need to passivate the surfaces, i.e. remove surface states from the bandgap. Since we have a lot of surface it may act as very efficient "recombination center" where we loose our light-generated minority carriers.
- We can only have a high-efficiency solar cell by definition if pretty much all minority carriers generated by the light will reach the front contact. This means that we *must* prevent internal recombination at point defects, other lattice defects, internal interfaces like grain boundaries *and* at the front and backside surface by all means.
- The picture shows how its done: deposit some layer (like $SiO_2$?)! Yes - but! Again, we have a crucial process where you don't want to share your know-how with your competitors. At present it appears that the company Suntech has found a particularly efficient way of doing this, all other companies try to catch up, but are clearly behind.

### Printing Contacts




- We now have to make the front side grid and the full-size backside contact. In other words, the tricky part is that we have to have a *structured* metal on the front side.
- No problem, you might think; we have done this before. Deposit the metal, structure by lithography and etching. Forget it. Far too expensive (not to mention too slow).
- We structure by **screen-printing** some goo or paste containing the desired metal particles on the solar cell. If you don't know how screen printing works in principle, look it up. We might do the same thing on the backside; there it is rather trivial because we do not need to structure.
- Sounds simple, is simple - but: It's a "rough" process, and if you damage the front just a tiny bit, your solar cell will be junk. What exactly do you use as the "paste"? Once more we have a special and crucial process with plenty of confidential know-how involved.

### Sintering Contacts




- So far we only have some paste in the proper places. To get a metallic contact, we have to **sinter** the paste - in the usual way we make, e.g., ceramics out of paste.
- All that it takes is heat - we have a second high-temperature process. Instead of putting batches of wafers into a conventional furnace, we rather run them on some ***conveyor band*** through a long tunnel furnace (similar to making bricks). Once more we have a solar-cell specific process, quite tricky in reality, that is done with some special equipment.
- If we are really smart and thrifty we will diffuse some boron into the backside at the same time in order to produce a **back-surface field** (***BSF***). What we are producing then is a $\mathbf{p^+p}$ "junction" that carries a (relatively small) electrical field with it that will repel all minority carriers (i.e. electrons) that strayed to the backside in their random walk, giving them a change to reconsider and to go to the front side where we want to collect them. In addition, a $\mathbf{p^+}$ doped backside makes for an easier ohmic contact.

Now we are almost done. We just put some anti-reflection coating on the surface that also serves as a protective layer, attach some leads ("wires") to strategic places so we can actually connect our solar cell to other, and, not to forget, measure everything we need to measure - within **1 s** - to characterize our individual solar cell electrically.

- Since we have already covered how we can measure a complete current-voltage characteristic in a short time, we will not go into this here any more.

## Famous Last Words

What is described above are the bare essentials of making bulk **Si** solar cells. It actually doesn't matter much at this level of unsophistication if you start with multi-crystalline **Si** or single crystals, the general processes are the same.

- A number of essential "tricks" have not been addressed at all. In particular, we must keep the impurities from being too harmful by using processes like "**gettering**" and "**hydrogen passivation**".
- Nevertheless, if you can come up with the cash (about **50 Mio $**) *and* if you have a source of state-of-the art multi-crystalline **Si** (hard to find in 2008), you can buy a complete solar cell factory from some companies that will churn out decent solar cells almost automatically. The only problem is that if you do only this, you will go broke in a few years because your competitors, who actually understand what they are doing, will have better and cheaper solar cells on the market.

So here is a prediction concerning the future:

**Nobody knows *how* we will make solar cells in 10 - 15 years from now.
All we know is that we will make 'em better, cheaper and that we will make far, far more then we make today**

- Here is some sage advice: Buy stock from the right solar cell company now, and you will be rich in **20** years. (If you send me large amounts of money, I might tell you which company is "right").