## V. DESIGN OF SILICON THICK FILM SOLAR CELL AND BASIS OF ITS EMERGENCE AS A SIGNIFICANG FACTOR IN LOCAL ELECTRICITY POWER GENERATION

As fossil fuels have become more prominent than any other fuel source, the United States has found itself relying heavily on foreign sources for its energy needs. However, fossil fuels are becoming scarcer and more expensive, so we need to find an alternative that lets us rely less on outside sources and more on ourselves. With the solar cell industry growing at a rate of 35% per year, we have decided that it is the most promising form of alternative energy on the market today (Learning about PV: The Myths of Solar Electricity, 2008). Therefore, we have constructed a plan to implement solar energy usage throughout the country, allowing us to generate some of our own energy, both locally and through the grid. This report will focus on the “local energy” part of this project implementation.

Grid-connected sources lose over 50% of the energy they produce in distribution (as shown in section III), thus local energy sources (which lose no energy in distribution) are extremely beneficial to their users. For this half of the project, we chose silicon as our primary material because it is more reliable in the long run, less toxic, and more abundant than other options, particularly cadmium telluride.

### TECHNICAL APPROACH

With this in mind, using the PC1D simulator, we created a device schematic, shown below:

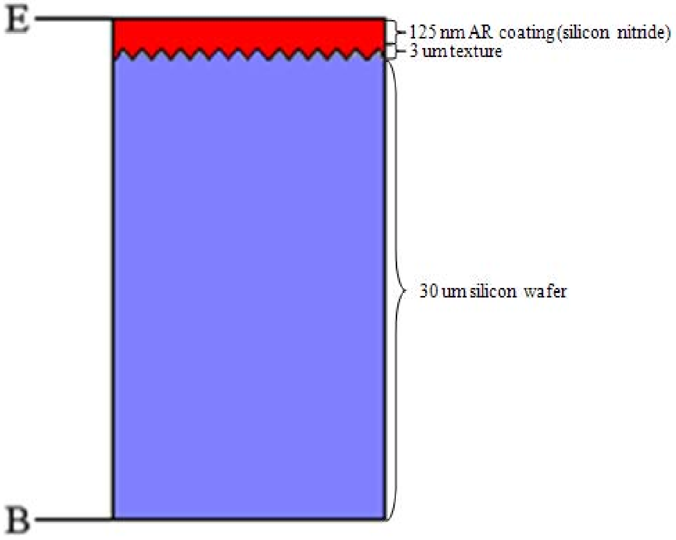

**Figure V.1: Cross-section of thick film silicon solar cell (not to scale)**

The data on the cell is as follows: each cell will have a surface area of 100 $cm^2$ (a standard size for solar cells) and will be 30 um thick (this is a thick film cell, which will be discussed more in detail later). The surface texture on each cell will be 10% of the overall thickness of the cell (which comes out to 3 um), since this texturing is enough to see significant results in overall efficiency. The p-type doping (background doping) will be set at 1x10^16 atoms/$cm^3$, since this creates a mix between a silicon wafer and thin film. Furthermore, the anti-reflective coating must be at a thickness that is ¼ of the peak input wavelength. Since the sun is a black-body spectrum, its peak occurs at approximately 500 nm, so the AR coating will be 125 nm in length. Also, for optimum efficiency, the index of refraction of the coating must be equal to the geometric mean of the indexes of refraction of the air and wafer. Since the index of air is 1 and that of silicon is about 4, the AR coating must have an index of approximately 2. We have therefore chosen silicon nitride as the material for our coating. This schematic results in a 15.21% efficiency, which is more than satisfactory, especially when we consider that it is about 5 times as efficient as nature itself (the efficiency of green plants during photosynthesis is about 3%).

We must now consider what exactly we did with the simulator and what assumptions were made. Though most parameters in the simulator remained at their default value, we did add texture and an anti-reflective coating, we reduced the thickness to 30 um (which constitutes a thick film cell), and we changed the first front diffusion doping to 1x10^19 atoms/cm$^3$ peak to make a p-n junction. We used an excitation from the ONE-SUN file, which averages the total incident power from the sun in one day. However, we are limited by the fact that only direct current flows from solar panels and most appliances in our households use alternating current, and by the fact that the sun only shines during the day, and without an energy storage technique, we are unable create electricity at night.

In creating this solar cell we must weigh the benefits within certain tradeoffs. The most important of these is the tradeoff between film thickness and carrier lifetime. The carrier diffusion length is the average distance a carrier travels in its lifetime, and it is equal to $\sqrt{(carrier\ diffusivity * lifetime)}$ (Stemmer, 1993). In this scenario, carrier diffusivity is 35 cm$^2$/s, and an average carrier lifetime is about 1x10$^{-6}$ s. This analysis results in a carrier diffusion length of 5.9x10$^{-5}$ m, or 59 micrometers. We want the carrier diffusion length to be greater than the thickness of the cell, since otherwise the carriers won't be able to make it from the front to the back of the cell. Therefore, thicker cells (i.e. wafers) run the risk of not being useful if their thickness is greater than the carrier diffusion length. From this perspective, it would seem that thin film cells are more beneficial. However, another important tradeoff is cost (particularly manufacturing cost). Thin film cells are much more expensive to manufacture than wafers, even though they are less risky in the film thickness vs. carrier lifetime tradeoff. We therefore decided that thick film cells, which are bigger than thin films but smaller than wafers, are the best option for our project.

The manufacturing process for thick film solar cells requires many steps, which is one reason why manufacturing costs are the thing that most affects the difference in price between different kinds of cells. First, silicon is extracted from the earth (where it makes up 28% of the crust), and purified by separating it from the other elements in the compound (i.e. if we extract sand, $SiO_2$, we separate the silicon from the oxygen). It is then doped with a group III element like boron to make it p-type material. Next comes the texturing, which creates microscopic pyramids that bounce light back onto the silicon surface in order to decrease the amount of light reflected. Then the n-doping is added (through a concentrated layer of phosphorous) to make the p-n junction, and the anti-reflective coating is applied to the surface to maximize the amount of light absorbed. Metal contacts are then attached to the top and bottom of the cell, and they work to collect the current generated in the cell. The cell then only needs to be assembled at this point, and it can then be used in a solar panel. Throughout this process, the cell is tested and purified multiple times in order to keep the final efficiency at a maximum (Solar Cell Manufacturing Plants, 2010).

The manufacturing process will originally rely on fossil fuels to power the solar cell factories, but our goal is to implement our project gradually so that as we build more factories, we can build them to run on solar power and we can convert older factories to run on solar power as well. Eventually, our project will run completely independently of fossil fuels.

One solar cell factory can be operational within 18 months of project approval and run at full capacity after another year (Solar Cell Technologies, 2010). This is fairly quick, meaning that as the project gets bigger, if it is received well, we can easily expand it by planning and running more factories. However, as stated before, our project (at least in its beginning stages) will be implemented gradually, to allow not only for improvements in technology, but also for increased public support of the project. As we build factories, we must also keep a few other things in mind: we must invest in research for converting DC current to AC (in order to rid ourselves of the DC limitation), and we must invest in research for solar energy storage techniques (in order to rid ourselves of the daylight limitation). In the meantime, one way to begin to free ourselves from the DC limitation is to invest in DC household appliances, where applicable (i.e. toasters and lights, but not televisions, refrigerators, or washing machines). In these ways we will work towards a future independent of foreign fossil fuel sources, and within 50 years, we will be able to supply 30% of the U.S.'s peak energy capacity, or 10% of our total generated electricity, through solar power sources.

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